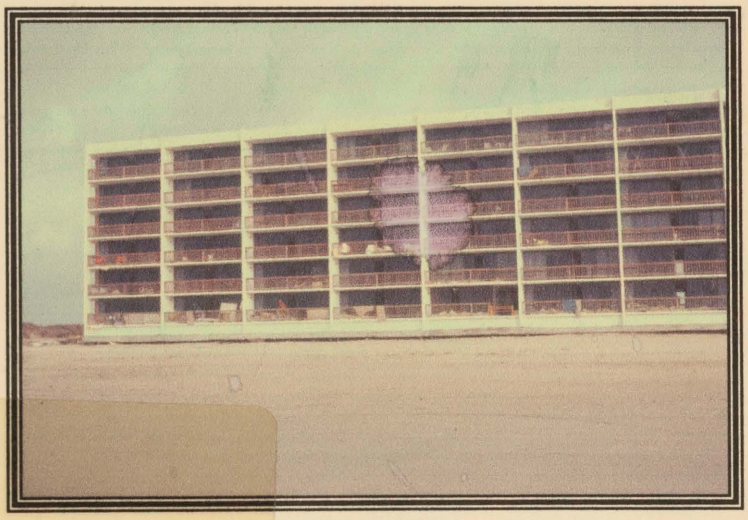
# 21 YEARS OF SHORELINE CHANGES ON MUSTANG ISLAND GULF BEACH

Anthony F. Amos
The University of Texas at Austin
MARINE SCIENCE INSTITUTE

*Gulf Shores, August 8, 1980, Pre-Hurricane Allen*



*Gulf Shores, August 11, 1980, Post-Hurricane Allen*

GB
459.25
A466
2000
MSL

# 21 YEARS OF SHORELINE CHANGES ON MUSTANG ISLAND GULF BEACH

Final Report

on

"Beach and Dune Erosion on a South Texas Barrier Island Beach Since 1979"

Texas General Land Office Contract 98-291R
Coastal Management Program, Cycle 3
Subrecipient Grant Agreement

by

Anthony F. Amos
The University of Texas at Austin
Marine Science Institute
750 Channel View Drive
Port Aransas, Texas 78373-5015 (USA)

THE LIBRARY
OF
THE UNIVERSITY
OF TEXAS
AT
AUSTIN

UT Technical report no. TR/00-002

A publication (or report) of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA87OZ0251

31 August 2000

1. INTRODUCTION ..... 3

2. HISTORY OF SURVEY AND METHODS ..... 5
2.1 The scope of the BEACHobs survey ..... 5
2.2 Beach width measurements ..... 5
2.3 Changes in methods after Hurricane Allen (1980) ..... 7
2.4 Field computer (1984) ..... 8
2.5 Electronic odometer (1984) ..... 11
2.6 Changes in methods after Hurricane Gilbert (1988) ..... 11
2.7 Data reduction and storage ..... 11

3. BEACH MANAGEMENT AND EFFECTS ON SURVEY MEASUREMENTS ..... 15
3.1. Vehicles on the beach ..... 17
3.2 Development of the beachfront ..... 17
3.3 Beach grading and weed removal ..... 20

4. EVENTS THAT SHAPED MUSTANG ISLAND GULF BEACH, 1979-2000 ..... 21
4.1 1979 ..... 21
4.2 1980 ..... 21
4.3 1981 ..... 23
4.4 1982 ..... 24
4.5 1983 ..... 24
4.6 1984 ..... 25
4.7 1985 ..... 25
4.8 1986 ..... 26
4.9 1987 ..... 26
4.10 1988 ..... 27
4.11 1989 ..... 28
4.12 1990 ..... 29
4.13 1991 ..... 29
4.14 1992 ..... 30
4.15 1993 ..... 31
4.16 1994 ..... 32
4.17 1995 ..... 32
4.18 1996 ..... 34
4.19 1997 ..... 35
4.20 1998 ..... 36
4.21 1999 ..... 37
4.22 2000 ..... 38

5. RESULTS OF GULF SHORES MEASUREMENTS ..... 39
5.1 The effect of tide, time, and beach profile ..... 39
5.2 Annual variation in beach widths at Gulf Shores ..... 46

5.3 The 21-year trend ..... 47
5.4 Summary of changes at Gulf Shores ..... 58

6. BEACH CHANGES AT OTHER LOCATIONS ..... 62
6.1 Changes by year ..... 63
6.1.1 Changes at Access Road #1 ..... 63
6.1.2 Changes at Mile 1 ..... 85
6.1.3 Changes at Mile 2 ..... 85
6.1.4 Changes at Mile 3 ..... 85
6.1.5 Changes at Gulf Shores ..... 85
6.1.6 Changes at Mile 4 ..... 85
6.1.7 Changes at Mile 5 ..... 85
6.1.8 Changes at Mile 6 ..... 92
6.1.9 Changes at Mile 7 ..... 92
6.1.10 Access Road #2 ..... 92
6.2 Changes by season ..... 92

7. CONTRIBUTION OF WEATHER TO CHANGES OBSERVED ON THE BEACH ..... 96
7.1 Effects of the annual weather cycle ..... 96
7.2 Effects of storms ..... 100

8. CONTRIBUTION OF HUMAN ACTIVITIES TO OBSERVED CHANGES ..... 114

9. SUMMARY ..... 114

10. REFERENCES ..... 116

Acknowledgments ..... 118

Appendices

I. Location of beach signs, mile markers, walkways and beach-front buildings along the survey transect in 1983, 1992, and 2000.

II.. Data diskette: shoreline, high tide line, and dune line measurements, September 1979 to June 2000 (see section 2.7.3 and Table 2, p. 13).

List of Figures

Gulf Shores condominium and beach before and after Hurricane Allen ..... Cover

Figure 1. Location map of BEACHobs survey site ..... 4

Figure 2. Log sheet from August 11, 1980, immediately after Hurricane Allen ..... 6

Figure 3. Computer equipment used in survey vehicle ..... 9

Figure 4. Page from field notebook ..... 10

Figure 5. Human activity on Mustang Island Gulf beach ..... 19

Figure 6. High altitude imagery of Mustang Island Gulf Beach survey site ..... 22

Figure 7. Schematic of measurements made at Gulf Shores condominium ..... 42

Figure 8. Calendar of predicted tides at Port Aransas, Texas, for May 2000 ..... 43

Figure 9. Profile of the beach made at Gulf Shores on October 3, 1984 ..... 44

Figure 10. Relationship between tide height and beach width at the time BEACHobs measurements are made (near dawn on each survey) ..... 45

Figure 11. Location of shoreline, driving lanes, and dune line at Gulf Shores: 1979-1981 ..... 48

Figure 12. 1982-1984 ..... 49

Figure 13. 1985-1987 ..... 50

Figure 14. 1988-1990 ..... 51

Figure 15. 1991-1993 ..... 52

Figure 16. 1994-1996 ..... 53

Figure 17. 1997-1999 ..... 54

Figure 18. 2000 ..... 55

Figure 19. Twenty-one-year series of changes to the beach and dunes at Gulf Shores: 1979-2000 ..... 56

Figure 20. Erosion/accretion of shoreline at Gulf Shores (using location of shoreline at time of measurement): 1979-2000 ..... 57

Figure 21. Erosion/accretion of shoreline at Gulf Shores (using location of the last high tide line): 1979-2000 ..... 59

Figure 22: Erosion/accretion of dunes at Gulf Shores: 1979-2000 ..... 60

Figure 23: Changes in beach width at Gulf Shores: 1979-2000 ..... 61

Figure 24: High-altitude image of Gulf Shores Condominium after Hurricane Allen, August 1980. ..... 62

Figure 25. Schematic of measurements made at Miles 0-7 and calculation of distances used in monitoring erosion/accretion ..... 64

Figure 26. Location of shoreline, high tide line, dunes and beach-front buildings on January 20, 2000 ..... 65

Figure 27. Location of dune line, high tide line, shoreline at Miles 0-7: 1983 ..... 66

Figure 28. 1984 ..... 67

Figure 29. 1985 ..... 68

Figure 30. 1986 ..... 69

Figure 31. 1987 ..... 70

Figure 32. 1988 ..... 71

Figure 33. 1989 ..... 72

Figure 34. 1990 ..... 73

Figure 35. 1991 ..... 74

Figure 36. 1992 ..... 75

Figure 37. 1993 ..... 76

Figure 38. 1994 ..... 77

Figure 39. 1995 ..... 78

Figure 40. 1996 ..... 79

Figure 41. 1997 ..... 80

Figure 42. 1998 ..... 81

Figure 43. 1999 ..... 82

Figure 44. Location of dune line, high tide line, shoreline at Miles 0-7: 2000 ..... 83

Figure 45. Seventeen years (1983-2000) of changes to the beach and dunes at Gulf Access Road #1 ..... 84

Figure 46. Mile 1 ..... 86

Figure 47. Mile 2 ..... 87

Figure 48. Mile 3 ..... 88

Figure 49. Gulf Shores ..... 89

Figure 50. Mile 4 ..... 90

Figure 51. Mile 5 ..... 91

Figure 52. Mile 6 ..... 93

Figure 53. Mile 7 ..... 94

Figure 54. Average location of dune line, high tide line, and shoreline at each site: 1989-2000 ..... 95

Figure 55. Seasonal changes in beach and swash zone widths relative to dunes: 1983-1984 ..... 97

Figure 56. 1991-1992 ..... 98

Figure 57. 1999-2000 ..... 99

Figure 58. Wind and sea conditions at Gulf Shores: 1979-1983 ..... 101

Figure 59. 1983-1987 ..... 102

Figure 60. 1987-1991 ..... 103

Figure 61. 1991-1995 ..... 104

Figure 62. 1995-1999 ..... 105

Figure 63. Actual versus predicted tides at Port Aransas during Hurricane Allen in 1980 (top) and Hurricane Gilbert in 1988 (bottom) ..... 106

Figure 64. Actual versus predicted tide at Port Aransas during Tropical Storm Charley in 1996 (top) and Tropical Storm Josephine in 1998 (bottom) ..... 107

Figure 65. Actual versus predicted tide at Port Aransas during Tropical Storm Frances in 1998 (top) and Hurricane Brett in 1999 (bottom) ..... 108

Figure 66. Dunes at Mile 4 during tides generated by Tropical Storm Josephine in 1996 ..... 109

List of Tables

Table 1. Typical format of NOTES files ..... 12

Table 2. Typical format of TOTALS files ..... 13

Table 3. Data recorded in TOTALS files pertinent to this report ..... 14

Table 4. BEACHobs beach width measurement sites ..... 16

Table 5. Location of man-made structures with beach access on Mustang Island Gulf beach in the BEACHobs study area as of June 2000 ..... 18

Table 6. The various datums used at Gulf Shores in doing beach width measurements ..... 41

Table 7. Dune erosion following Tropical Storm Josephine ..... 111

Table 8. List of tropical weather events and their effect on the beach, as recorded during BEACHobs from 1979-2000 ..... 112

# 21 YEARS OF SHORELINE CHANGES ON MUSTANG ISLAND GULF BEACH

Anthony F. Amos
The University of Texas at Austin
Marine Science Institute, 750 Channel View Drive, Port Aransas, TX 78373-5015
afamos@utmsi.utexas.edu

## 1. INTRODUCTION

In April 1978, a survey (BEACHobs) of Mustang Island Gulf beach was initiated by the author. The on-going survey is done bi-daily and extends a distance of 12.1 km from Gulf Access Road #1 to Gulf Access Road #2 (Fig. 1). BEACHobs was initially done to monitor the bird populations on this section of the beach which, in 1978, was less-visited by beach-goers than other sections of Mustang Island and North Padre Island Gulf beaches. This was primarily because it is distant from population centers in Port Aransas and Corpus Christi and the only beach access was by automobile. Also, the distance between access roads (7.25 miles) deterred people from driving its length. In 1978, however, a building boom was about to start on Mustang Island and the concept of the survey was to record bird population response to disturbance as the beach became more accessible to people via the beachfront condominiums.

The survey soon expanded to include counts of people and automobiles, items of marine debris, measurements of surf zone oceanographic and beach weather conditions, simple measurements of beach widths, and location of tide lines, berms, driving lanes, and the dunes. Erosion/ accretion and other beach morphological measurements reported here were made from September 1979 through June 2000 at a single location, and from September 1988 through June 2000 at eight additional locations spaced at approximately one-mile intervals. Mustang Island has been the site of previous morphological studies (Davis and Fox, 1972; Davis, 1972; Davis, 1978), all using the standard beach profiling method (Emery, 1961). Shoreline and dune line changes have also been documented for many years by the University of Texas' Bureau of Economic Geology (Morton and Pieper, 1977) and more recently by Morton et al. (1993). Factors affecting beach erosion have been measured by Snedden and Nummedal (1990) and Snedden et al. (1988). All of these studies have either done measurements at lengthy intervals or have been devoted to repeated measurements over a short time interval. The present study is unique in the number (>3,000), frequency (bi-daily), and duration (21 years) of measurements made. It was not possible, however, to use standard beach-profiling methods because all surveys were done by one person (the author). Instead, simple beach width measurements were made, first by pacing and later using a surveyor's wheel. To give an idea of the scope of the data base, 71,699 separate measurements required walking a total of 2,312 km (1,437 miles) laterally from dune to shoreline. It should be noted that BEACHobs is a personal effort to understand a Texas barrier island Gulf beach over a long time period. It has not been funded by any agency and I have personally done all but a handful of the >3,000 surveys. Vehicles, computers and most of

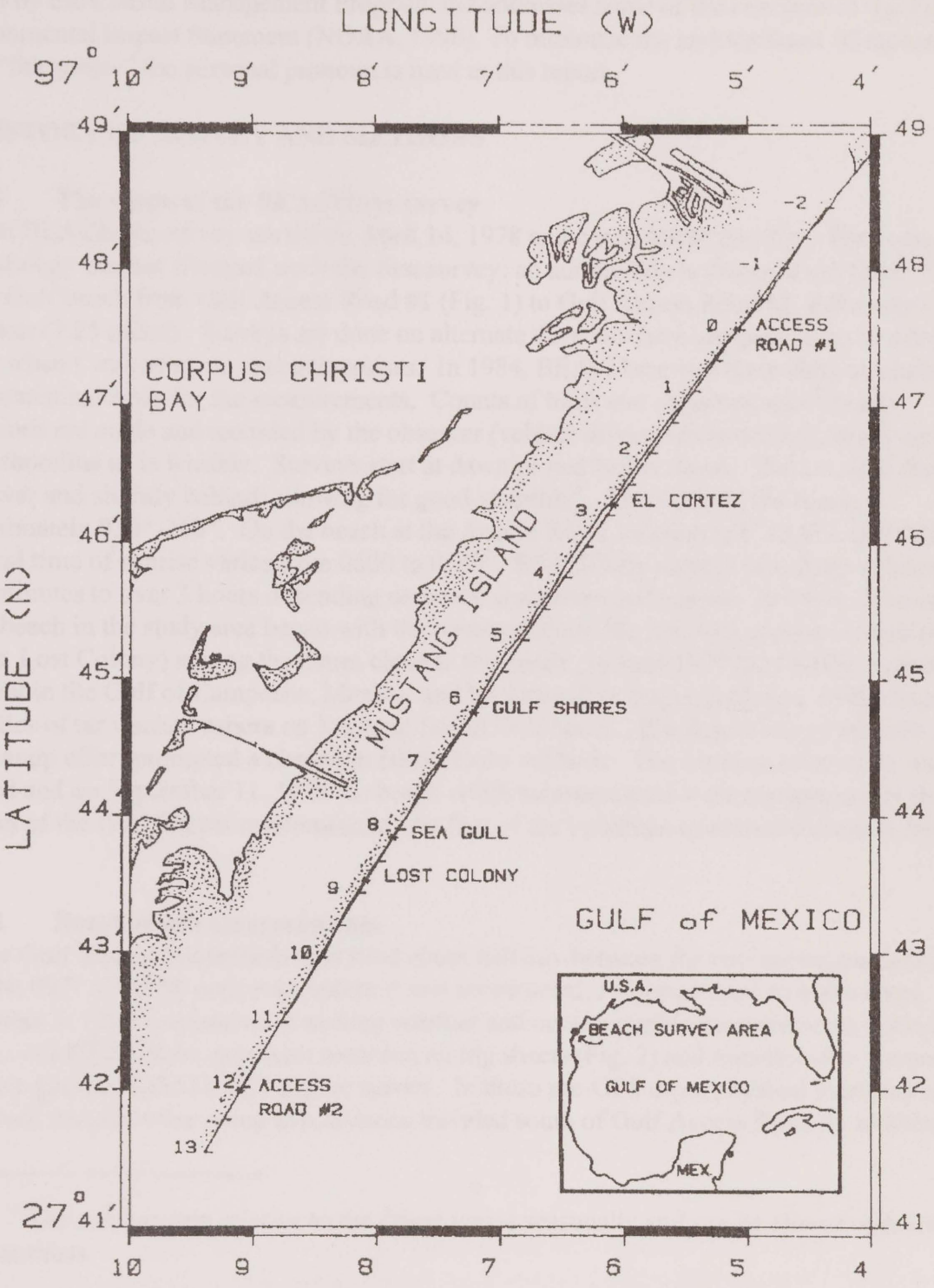



Figure 1. BEACHobs survey site showing distance along transect in 1 km intervals from Gulf Access Road #1 and the condominiums that were constructed when the beach width measurements were started in 1979.

the equipment used have been personally funded. The present analysis of the erosion data was funded by the Coastal Management Program and addresses some of the concerns in the Final Environmental Impact Statement (NOAA, 1996). To minimize the awkwardness of repeatedly using "the author" the personal pronoun is used in this report.

## 2. HISTORY OF SURVEY AND METHODS

### 2.1 The scope of the BEACHobs survey

The BEACHobs survey started on April 14, 1978 and continues to this day. The basic methodology has not changed since the first survey: an automobile is driven south along Mustang Island Gulf beach from Gulf Access Road #1 (Fig. 1) to Gulf Access Road #2, a distance of 11.83 km (7.25 miles). Surveys are done on alternate days but there are gaps of up to a few weeks when I was away on research cruises. In 1984, BEACHobs was done daily to establish some statistical basis for the measurements. Counts of birds and observations of beach conditions are made and recorded by the observer (vehicle driver) while driving slowly as close to the shoreline as is feasible. Surveys start at dawn or just before dawn. The sun is to the left of the driver and slightly behind, allowing for good visibility[1]. The strike of the beach is approximately 030°-210°. On the beach at the Access Rd #1 location (27°43.8'N, 097°06.6'W) the local time of sunrise varies from 0600 to 0740[2]. BEACHobs surveys take from a minimum of 40 minutes to over 3 hours depending on beach conditions and season. In 1978, development of the beach in the study area began with the construction of the first two condominiums (Gulf Shores, Lost Colony) among the dunes close to the beach. In June 1979 the IXTOC I platform blew out in the Gulf of Campeche, Mexico, and by September that year (Amos, 1980) huge quantities of tar washed ashore on Mustang Island Gulf beach. The deposition of tar mats and the cleanup effort prompted a change in BEACHobs methods. The location of tar mats was mapped and on September 11, 1979 the beach width measurements were commenced at the location of the Gulf Shores condominium, the first of the buildings constructed close to the beach.

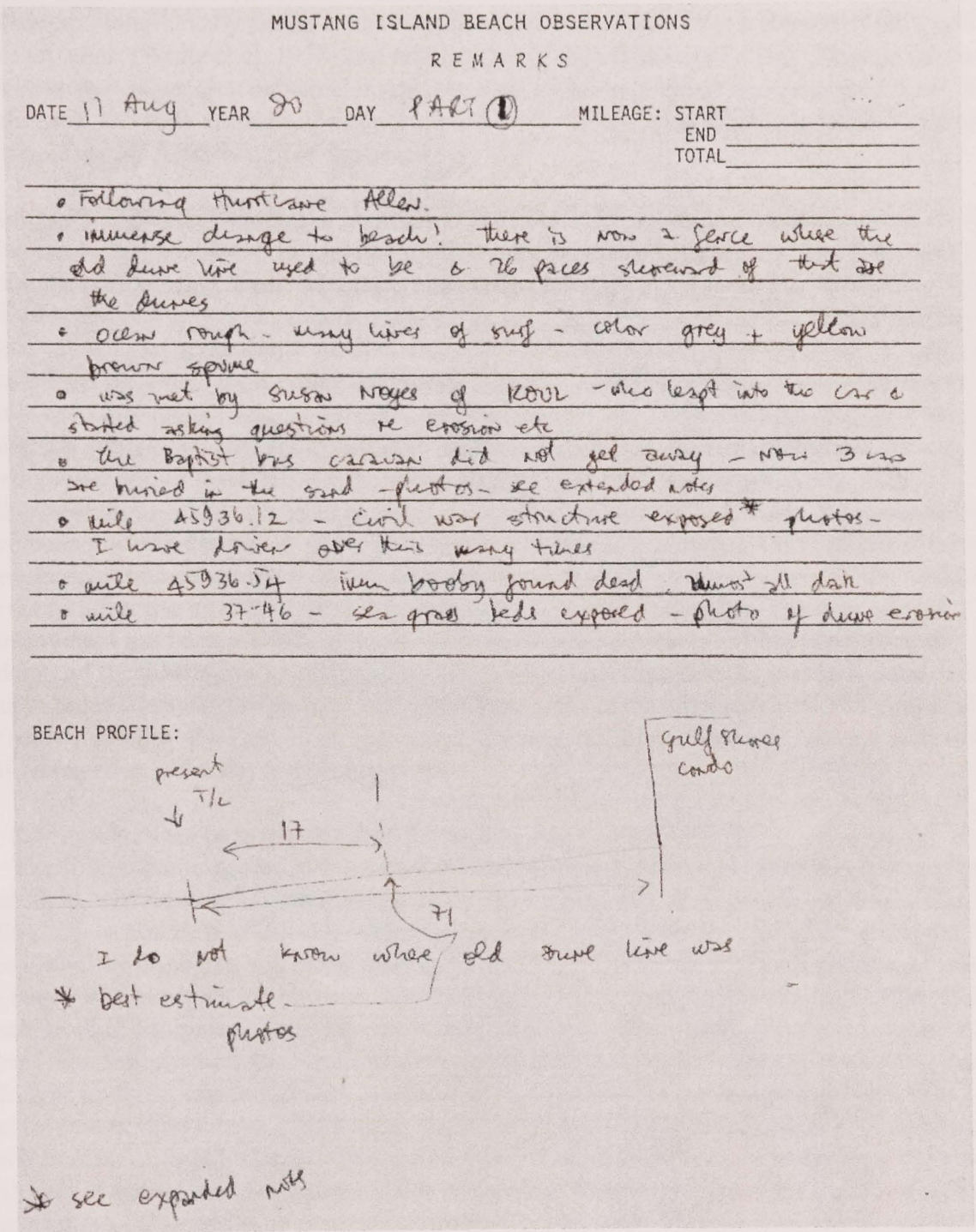
### 2.2 Beach width measurements

The Gulf Shores condominium is sited about halfway between the two access roads at 27° 44.83'N; 097° 07.17'W and, even before it was constructed, I stopped there to make notes. On September 3, 1980 I commenced making weather and oceanographic measurements at Gulf Shores. All BEACHobs data were recorded on log sheets (Fig. 2) and transferred to a computer (Hewlett-Packard 9825) following the survey. In those pre-GPS days, physical locations along the survey transect were noted as a distance traveled south of Gulf Access Road #1 as indicated

---

[1] The sun location relative to the driver varies seasonally and can be almost opposite the driver at times.

[2] Before 1986, Central Daylight Savings Time (CDST) started on the last Sunday in April. After that, CDST commenced on the first Sunday in April. This has ramifications on the relationship between starting time and the tidal cycle.



MUSTANG ISLAND BEACH OBSERVATIONS

REMARKS

DATE 11 Aug YEAR 80 DAY PART (1) MILEAGE: START
END
TOTAL

- Following Hurricane Allen.
- immense change to beach! there is now a fence where the old dune line used to be & 26 paces shoreward of that are the dunes
- ocean rough - many lines of surf - color grey + yellow brown spume
- was met by Susan Noyes of KRUL - she leapt into the car & started asking questions re erosion etc
- the Baptist boys caravan did not get away - now 3 cars are buried in the sand - photos - see extended notes
- mile 45936.12 - civil war structure exposed * photos - I have driven over this many times
- mile 45936.54 iron booby found dead. Must all date
- mile 37-46 - sea grass beds exposed - photo of dune erosion

BEACH PROFILE:

present T/L

17

71

Gulf Shores condo

I do not know where old dune line was

* best estimate - photos

* see expanded note

Figure 2. Log sheet from 11 August 1980, immediately after Hurricane Allen. Note remarks about beach conditions and error on location of dunes after the storm (should be 26 paces landward (not shoreward) of the posts. Also sea "grass beds" were actually old gorgonian stalks.

on the vehicle's odometer, read to the nearest 1/100th mile. This distance was converted to latitude and longitude by fitting a curve to the shoreline as taken from a Bureau of Economic Geology chart (White et al. 1978) and relating that to the odometer reading. Because odometer mileages vary depending on vehicle used, tire size, inflation pressure and amount of wear, as well as slippage on sandy surfaces, the key locations on the beach were ultimately measured directly by wheeling the entire length of the beach.

Three basic width measurements are made at Gulf Shores: starting at the current shoreline (SL), the width to the most recent strand line or high-tide line (HTL), to the dune line (DL), and to a datum post (DATUM) or other semi-permanent structure (in the case of Gulf Shores, the front wall of the building is used, although it is easier to measure to the walkway, the distance from that to the wall being known). At first, distances were measured by pacing, using an easy gait to pace off the distance. I have done the pacing throughout the survey and, when a surveyor's wheel was used for the first time (July 1, 1981) the paces were calibrated against the wheel for numerous subsequent surveys to establish a mean pace length. From these basic distances, the absolute location of the shoreline, dune line and high tide are determined. Much later, a differential survey GPS was used to obtain a "benchmark" for the DATUM. All measurements have been made in meters. In addition to the three main measurements, the location of weed lines, berms, runnels, and driving lanes are measured on each survey. Of course, the location of the shoreline at the time of each survey depends on the state of the tide. The time of each measurement has been recorded from the start and a considerable effort has been made to understand the tidal cycle on the Mustang Island shoreline. Because the survey is done at dawn (Gulf Shores is usually reached an hour after dawn), due to our tropical/equatorial tidal cycle, and for several months at a time, high tide occurs at or near the time of measurement. Later, low tide will be experienced at the measurement time.

### 2.3 Changes in methods after Hurricane Allen (1980)

The first major erosional event occurred with Hurricane Allen that came ashore near Port Mansfield, 120 miles to the south of the study site on the night of August 9-10, 1980 (Ellis, 1986). Up to that time, distances were measured only to the dune line. I had observed that the location of the dune line was fairly constant and my initial concern was to discover how much of the beach was available for bird use. Vehicle traffic was light and there was little effort to use beach grading equipment in the late seventies. Hurricane Allen changed that perception. At Gulf shores (cover illustration) the beach was swept clean of everything including walkways, dunes, and signs up to the condominium. A classic storm beach resulted (Nummedal, 1982, Fig. 3-38). For the next several weeks, efforts were made by the condominium management to stabilize the beach in front of their property. This included erection of snow fences and the importation of sand. For a while I could measure directly to the Gulf Shores wall, but after that I had to shift my reference DATUM locations as various barriers were erected. This has been a constant problem in doing the surveys. Numerous DATUM changes have occurred and occur to this day.

Finding a suitable datum post was also a problem when, on November 11, 1983, I decided to measure beach changes at other locations along the study beach. Hurricane Allen revealed

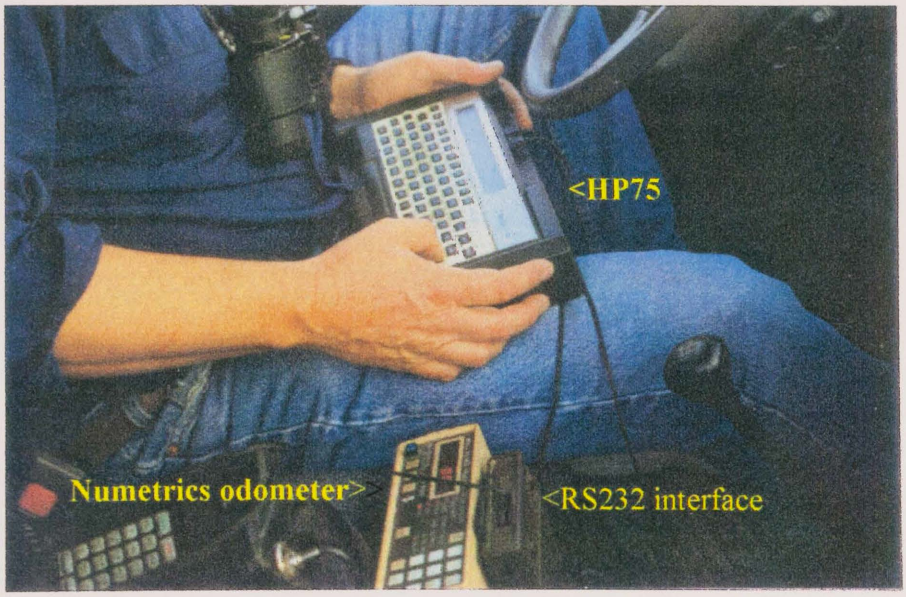
several old metal posts, both in the dunes that might have marked an old dune line and near the shoreline. I used the posts and other semi-permanent structures to establish eight additional locations to measure beach widths to the dune line. Starting at Gulf Access Road #1, each location was separated by approximately one mile. Again, the main object was to see how the beach width (distance between shoreline and dune line) and high tide line varied over time. At that time I had no fixed datum. Variations in beach width measurements could be due to erosion at the shoreline or by dune encroachment or recession.

### 2.4 Field computer (1984)

The next innovation was the method of recording all data, including beach widths. A Hewlett Packard HP75C hand-held computer was used starting on February 1, 1984 (Fig. 3a). Despite huge improvements in portable computers since 1984, the HP 75 is still used to conduct the surveys. It has simplicity, reliability and excellent battery life and literally millions of keystrokes have been entered in the past 16 years. A series of HP BASIC programs were written to allow a reconfiguration of the keyboard so that single keystroke entries of various items (birds, people, etc.) could be made. In addition, notes could be entered at each of the mile posts and at Gulf Shores, and at any time a notable event occurred during the course of the survey. Each note has one or more 4-letter codes entered to allow easy sorting of the notes into categories later. At each mile post the HP prompts for entry of the three basic measurements, automatically tags the data with a time stamp and automatically flags whether the measurement is made by pacing or by surveyor's wheel (pacing is an integer entry, wheel measurements are done to the nearest 0.1 meter). At Gulf Shores an additional prompt is given for entry of the berm, weed-line data, each coded). At the end of the survey, the HP totals and displays the data item-by-item allowing the operator to note any egregious errors. At the laboratory, the data are downloaded to a PC (at first an HP Series 100, followed by IBM PC, XT, AT, and the various 86 versions to the Pentium era and beyond). It has been a challenge to archive and keep current the various data sets as computer technology has advanced so rapidly. For example, the data were first recorded on HP 8" floppy disks with the 9825 series. Later, the first 3-1/2" diskettes with a capacity of 250 KB were used but these could only be accessed using HP floppy disk readers. Iomega 10-MB 8" removable disk cartridges were used but these were superceded by 20-MB 8" cartridges, then 45-MB Bernoulli disks (5-1/4"), 150-MB Bernoullis, and 100-MB 3-1/2" Zip disks, which are still used today.

The drawback to using the HP75 for the basic field data collection is that its memory is only 24 KB and 13 KB are occupied by the program alone. Innovative programming methods had to be used to keep data files to a minimum (e.g. data elements are stored as single ASCII characters, allowing as many as 240 separate categories of items to be identified), and that has carried over to the archiving of this information. There are still some notes that have not been transcribed from the log sheets to the computer from the early years. To backup the data, hard copies are printed out and archived in bound yearly volumes. Condensed versions are printed in a format that allows pasting in my field notebooks in lieu of the original hand-written notes (Fig. 4). Copies of all Zip disks are kept in a separate location to the originals, volumes, and notebooks.

a)




b)

Figure 3. a) HP75 as used in survey vehicle. b) Numetrics electronic odometer (bottom center) with RS232 interface and HPIL (interface loop) connecting to the computer.

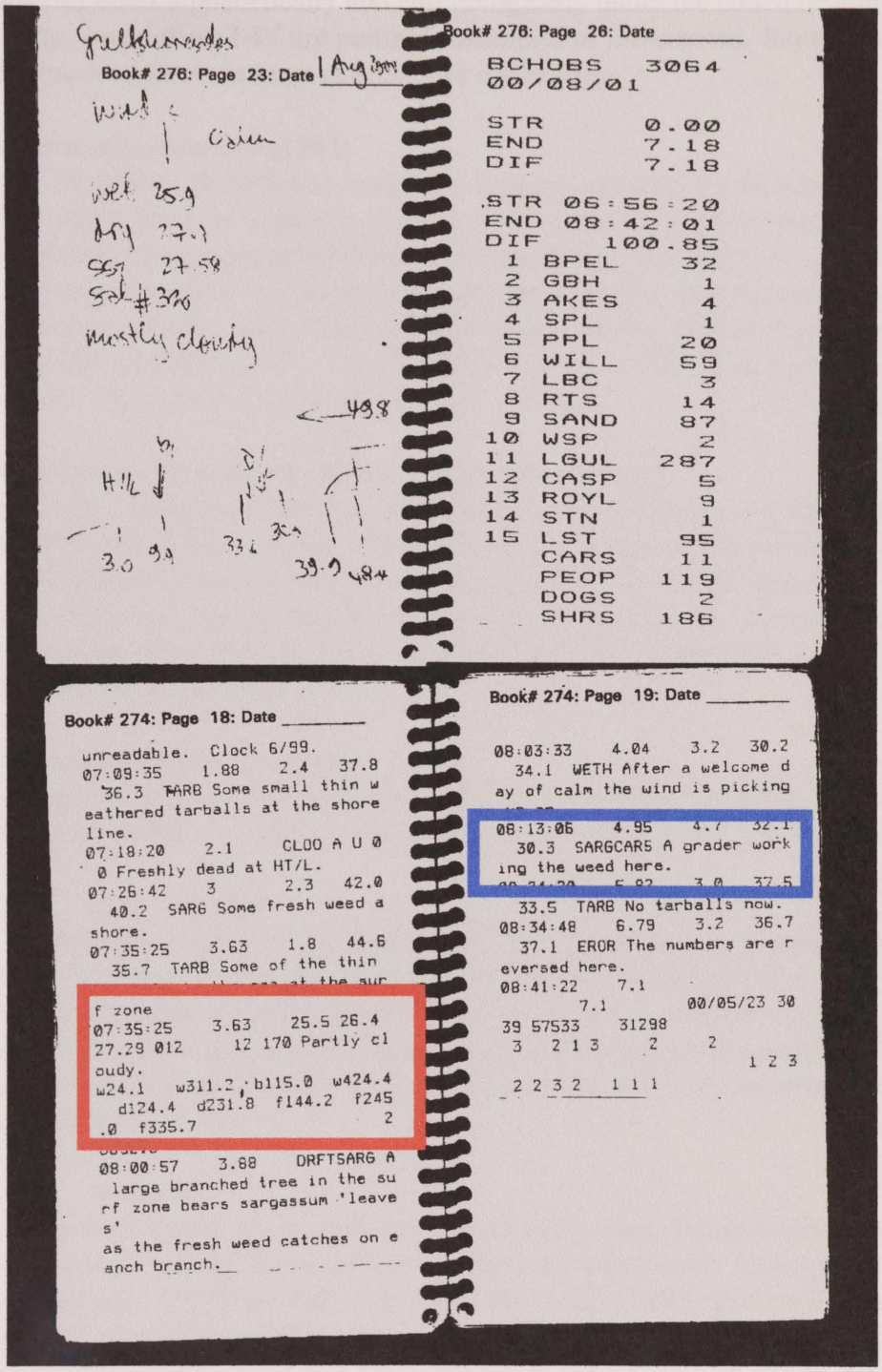



Figure 4 BEACHobs Field notebooks. Computer printouts are pasted in the notebooks following each survey. Gulf shores data outlined in red. Mile 5 data in blue. Diagram of Gulf Shores beach conditions are drawn at time of observation.

A program lists all notes alphabetically and chronologically under the coded headings and these are bound yearly. Appendices I-IV are pertinent examples of these notes. Notebooks and disks are taken with me whenever we must evacuate for a hurricane.

### 2.5 Electronic odometer (1984)

On January 26, 1984 a NuMetrics electronic odometer was used for the first time (Fig. 3b). This unit takes output from the vehicle's odometer cable and converts it to distance traveled in meters (calibrated against a measured distance). Output from the NuMetrics is input to an RS232 HP-IB interface and the record is stamped automatically with time and distance data at intervals and whenever a note is made. Unfortunately, the corrosive atmosphere on the beach has not been kind to vehicles and equipment alike. The NuMetrics and its successor have not been used on the latest vehicle. I have used up a dozen surveyor's wheels.

### 2.6 Changes in methods after Hurricane Gilbert (1988)

After Hurricane Allen (September 14, 1980) I added a third measurement to those done at mile intervals along the survey transect. Datum posts were located as close as possible to each mile and a measurement from shoreline to datum post was made. Since then the methods have been essentially the same. On January 5, 1994 the City of Port Aransas erected substantial posts at 1/10-mile intervals within the city limits. This has made the beach width measurements in that area easier to do and more reliable.

### 2.7 Data reduction and storage

After each survey, the raw data are downloaded into three files: Raw Data (converted from ASCII characters to readable codes) in chronological sequence; Notes; Totals.

#### 2.7.1 Raw data files

All data are in ASCII or text format to allow reading by any program. For archiving, these minimally processed files are stored in folders BIRDRAW, BIRDNOTE, and BIRDTOTL, with subdirectories for each year (e.g. BDZ99, NOT99, TOT99). Individual daily files are named by the Julian day with no extension (a holdover from "pre-extension computers"). The raw data files are of minor interest to this report, although they are flagged with distance data, they contain the counted items of BEACHobs.

#### 2.7.2 Notes files

These files contain the information on each mile where beach widths are measured, including Gulf Shores, and any notes pertinent to those measurements. Principle among these are the following codes: BCH=general notes about the beach, CARS=vehicle information (includes any type of vehicle, including the graders and other heavy machinery), DUNE=dunes, EROR=errors made during surveys, METH=methods, POST=info about datum (and other posts), SARG= *Sargassum* weed, SEAS=notes about sea conditions, TIDE=notes about the state of the tide, WETH=weather. A typical recent Notes file is given in Table 1 below. Only those notes are included where beach width measurements were made or where the note establishes basic data used in this report.

Table 1. Typical format of NOTES files

```
C TIME (L)  DIST  HT/L  DATUM DUNE   DATE     OBS# MILEAGE SECONDS
1 06:53:45  0.00   2.3  102.0  58.2  00/06/28 3049 59108    24780
                                     CODE(S)       NOTES
1 07:05:40  0.95   4.0   59.6  45.2  DUNESARGMETH It is getting more difficult
   to measure at mile1 because of the piles of weed dumped here.
1 07:16:47  1.91   1.3   42.9  40.6  SARGBCH  Looks like there is an effort to
   extend the weed cleaning.  Ugly heaps of weed and heavy equipment tracks
   mar the beach scene.
1 07:32:44  3.06   1.9   46.1  43.1  GARBGBOT Looks like someone has
   hand-picked the garbage.
GULF SHORES OBS
1 07:44:45  3.68   2.4   48.7  41.5  PEOP Woman from Austin talks to me at
   length about the beach
C TIME (L) DIST     WET  DRY  SST   SAL#  WSPD WDIR WEATHER 6 07:44:45  3.68
 25.7 27.2 28.17 027     11 180 Partly cloudy.
C BERM1   BERM2   WEED2   DRIVE1  DRIVE2  FENCE1 FENCE2   FENCE3       SECONDS
6 b11.5   b210.1  w227.5  d131.5  d237.5  f148.8  f248.6  f341.5       29830.5
C TIME (L) DIST   HT/L  DATUM  DUNE  CODE(S) NOTES
1 08:20:37  4.09   2.5   37.6  38.4  DUNE The dunes look awful with ugly heaps
of weed & sand the length of the beach.
1 08:30:45  5.00   1.5   39.7  37.5  CONDCARSSARG The grader is working at
   SeaGull
1 08:39:43  5.88   5.8   48.9  44.1  CARSPEOP Six trucks and maybe 8 people
   here on a surf fishing camp.
1 08:52:58  6.85   2.7   42.1  38.1  AMOS Why can I never think of anything
   to say here?
1 08:59:29  7.18 7.18       00/06/28 3049 59115    32393
DEBRIS ESTIMATES
7                      3   1 1 4    2                        2          2
3 3 4 2 2       1 1 2
```

**Key**: C= internal code indicating type of note, DIST=odometer reading at time note was made (highlighted where beach width measurements were made), HT/L=distance to high tide line, DATUM=to datum post or marker, DUNE=distance to dune line (all distances measured relative to present shoreline), OBS#consecutive BEACHobs observation number, MILEAGE=mileage on current vehicle used, SECONDS=number of seconds elapsed from midnight local time, CODE(S)=one or more 4-character codes to categorize note and used later for grouping like notes. The following pertain to Gulf Shores only: WET, DRY=psychrometer readings of air temperature (C), SST=sea surface temperature, SAL#=number of salinity sample bottle, WSPD=wind speed (kt), WDIR=wind direction (from), WEATHER=brief current weather conditions description, BERM1,2 etc.=distance to successive berms, WEED2,3 etc.=distance to various weed (strand) lines (as a holdover from memory saving days, if first weed line is WEED2, it is assumed that WEED1 was at the shoreline), DRIVE1=distance to seaward edge of driving lane, DRIVE2=distance to shoreward edge of driving lane (width of driving lane will be DRIVE2 minus DRIVE1; if there is more than one driving lane it will be DRIVE3, DRIVE4, etc.), FENCE1=distance shoreline to first fence line, FENCE2=distance first fence line to shoreline (two measurements are made from shoreline to datum, first in one direction, then the other; actual distance used is a mean of the two), FENCE3=distance to dune line (note, this is a holdover from the post-Hurricane Allen time when I measured to fence lines; these have now been engulfed by the dunes or destroyed but the designation remains). The actual way data are recorded is in the form b112.2=12.2 meters to first berm, etc. DEBRIS ESTIMATES are not generally of interest to this report.

### 2.7.3 Totals files

The files contain the total numbers of various items counted during the surveys and also other parameters pertinent to the survey. Each item in the totals list is identified by its numerical code. A master list of codes and their explanation is maintained in the data base. Only those of interest to beach measurements are given in Table 3.

The raw data, notes, and totals files are generated immediately following each survey. At intervals, further data reduction and data management programs are employed for archiving and analyzing individual aspects of this multi-faceted survey. In particular, program ONEYEAR separates each of the Totals files into individual files for each category and appends new data to that file (e.g. code 54, distance from shoreline to high tide line, becomes file 54 [again, naming convention was devised in the pre-PC days but has served well for data analysis]). The key to the time-series approach is to relate the data to a time variable that remains true regardless of year, month, and day. For these data, time zero was set at January 1, 1978 and the time stamp used is "YEARDAY," the number of days elapsed since that date. Many routines have been written to relate each individual measurement to yearday, and the reverse of that process, to relate back to familiar calendar dates. It is remarkably easy to lose track of data that is collected over decadal time periods. These numerically coded files relate only to data collected at Gulf Shores. The other beach width measurement files are handled differently, but still use the yearday time stamp. Routines extract data from the Notes files for each mile where measurements are made and combine them into three sets of additional files:

1. HITIDE.YY Distance from shoreline to hightide line at all locations, including Gulf Shores.
2. DATUM.YY Distance from shoreline to datum at all locations, including Gulf Shores.
3. DUNE.YY Distance from shoreline to dune line at all locations, including Gulf Shores.

In each case, YY=last two digits of the year**. The time is recorded to relate the measurement to the state of the tide at the time of measurement. The format (Table 2) of these files, which are submitted on electronic media (Appendix II), is given below for file DATUM99. The HITIDE and DUNE files are identically formatted:

Table 2. Typical format of TOTALS files.

```
YRDY TIME0 FTR0 TIME1 FTR1 TIME2 FTR2 TIME3 FTR3 TIMEG FTRG TIME4 FTR4
7661 7.25  93.0  7.47 48.2 7.64  37.5  7.87 37.3  8.11 38.2  8.59 26.4
Line continued...
TIME5  FTR5 TIME6  FTR6 TIME7  FTR7
8.72  39.4  8.91  37.6  9.26  39.6
Key: YRDAY=yearday, TimeN=local time in hours at mile n (G=Gulf Shores) where
measurement was made, FTRn=width from shoreline (m) to feature at mile n,
where FTR=HITIDE, DATUM, or DUNE.
```

**The HP75 did not have a "Y2K" problem. Also, I wrote all the time/date handling routines many years ago to consider the Y2K difficulties. I pondered whether to use the "*.00" extension for year 2000 and decided to do so, but all processing routines recognize any extension t<79 to be chronologically later than 1979.

Table 3. Data recorded in TOTALS files pertinent to this report.

ALPH = 4-character alphanumeric code; NUM = numerical code

| GENERAL OBSERVATION PARAMETERS | | |
|---|---|---|
| **ALPH** | **NUM** | **EXPLANATION** |
| OBS# | 44 | OBSERVATION NUMBER |
| JULN | 45 | JULIAN DAY STARTING 1 JAN 1978 |
| PACG | 8 | PACING=1/WHEEL=2 |
| NUMT | 27 | NUMETRICS:1=NOT USED |
| DIST | 57 | DISTANCE OF OBSERVATION IN MILES AND 1/1000ths |
| TIME | 56 | TIME OF OBSERVATION IN MINUTES AND 1/100ths |
| KILO | 236 | # OF 30-SECOND KILOMETER MARKS |

| WEATHER AND SEA CONDITIONS | | |
|---|---|---|
| **ALPH** | **NUM** | **EXPLANATION** |
| SEAS | 257 | SEA STATE |
| WSPD | 52 | WIND SPEED |
| WDIR | 53 | WIND DIRECTION |
| NVEC | 298 | N/S WIND VECTORS (m/sec) |
| ONSH | 13 | ONSHORE WINDS (m/sec) |
| SSS | 51 | SEA-SURFACE SALINITY |
| SST | 50 | SEA-SURFACE TEMPERATURE |
| WET | 48 | AIR TEMPERATURE (WET BULB READING) |
| DRY | 49 | AIR TEMPERATURE (DRY BULB READING) |
| RELH | 58 | RELATIVE HUMIDITY (%) |

| BEACH WIDTHS AT GULF SHORES | | |
|---|---|---|
| **ALPH** | **NUM** | **EXPLANATION** |
| HTL | 54 | SHORELINE TO HIGH-TIDE LINE |
| DL | 55 | SHORELINE TO DATUM/DUNE LINE |
| DL-H | 239 | DUNE LINE TO HIGH-TIDE LINE |
| DL-S | 240 | DUNE LINE TO SHORELINE |

| INFORMATION ON BEACH USAGE | | |
|---|---|---|
| **ALPH** | **NUM** | **EXPLANATION** |
| CTOT | 312 | TOTAL # CARS |
| PTOT | 312 | TOTAL # PEOPLE |
| PCRT | 313 | PEOPLE/CARS RATIO |
| PPG | 301 | GASOLINE; PRICE PER GALLON** |

**Recorded from my vehicle usage to see if fluctuations in gasoline prices are reflected by the number of vehicles and people on the beach (inconclusive).

## 2.8 Measurement uncertainties and errors

### 2.8.1 Pacing

The earlier width measurements were done by pacing rather than measuring with a surveyor's wheel. Also, there were periods throughout the survey when pacing was used (forgot wheel, wheel malfunctioning, new wheel on order). My paces were calculated from a set of survey comparisons. One "Amos" pace=0.79m (N=52, $R^2$=0.9975, SD=1.86).

### 2.8.2 Surveyor's wheel

Uncertainties occur when there is build up of sand on the wheel rim, especially during the early period when beach tar was pervasive and stuck to the rim. The wheel was cleaned regularly. The wheel can slip on dry sand and skip on a rutted surface. The measurement should be made normal to the beach and dune trend. This was accomplished by sighting and comparison measurements showed that ensuing off-angle errors were small.

### 2.8.3 Locating the shoreline and dune line

Depending on wave run-up, the shoreline was taken as the mean location of the swash zone. In rough weather, errors in determining where the shoreline terminated were greater than in calm weather. The dune line also presented difficulties. During erosional periods the dune wall was steep and measurement easy. As dunes grew, I took the dune line to be where the slope of the surface changed from the back-shore gradient. Generally, this was also the vegetation line. I ignored the advancing tendrils of morning glory onto the flat back-beach. Beach grading also complicated the measurements. Ridges formed by grading adjacent to the dunes eventually became the dune line as sand built up between the ridge and dunes.

### 2.8.4 Destruction or relocation of datum posts

This is a continuing problem because almost all structures on the beach are ephemeral over periods of years (see Appendix I). On occasion, I could anticipate a change and made measurements between old and new datum posts to correct the data in the long run; sometimes I had to make estimates of the new locations.

# 3. BEACH MANAGEMENT AND EFFECTS ON SURVEY MEASUREMENTS

Three entities have management over Mustang Island Gulf beach in the survey area: the City of Port Aransas, Nueces County, and the City of Corpus Christi. Various limits and annexations have changed the areas controlled by each of these since 1978. At the present, the Port Aransas city limits extends 3.5 miles south of Access Road #1 (Marker 27 to 62). Nueces County jurisdiction extends from there to Access Road #2 and beyond, but recently, the City of Corpus Christi limits fall between Mile 6 and 7. Table 4 shows the locations of the beach width sites and the entities that manage the beach at each site.

At the start of BEACHobs, Nueces County maintained the entire beach length in the survey area. Markers started at Mile 17 south of Access Rd #1, and were located at one mile intervals until Mile 10, but there has been a tortuous history of markers and datums used in this survey. I used

Table 4. BEAChobs beach width measurement sites.

| Mile Number | Datum | Distance S of Access Rd 1 (meters) | Distance S of Access Rd 1 (miles) | Location Lat(N)/Long(W) |
|---|---|---|---|---|
| Port Aransas City Limits | | | | |
| 0 | Apron of Access Road #1 | 0.0 | 0.00 | 27° 47.57' 097° 05.09' |
| 1 | Marker 35 | 1560.8 | 0.97 | 27° 46.86' 097° 05.64' |
| 2 | Marker 45 | 3154.4 | 1.96 | 27° 46.14' 097° 06.20' |
| 3 | Marker 57 | 5010.8 | 3.11 | 27° 45.29' 097° 06.83' |
| Nueces County Area | | | | |
| 3.65 | Gulf Shores Condo | 5996.6 | 3.73 | 27° 44.83' 097° 07.17' |
| 4 | BeachWalk walkway | 6719.5 | 4.18 | 27° 44.50' 097° 07.41' |
| 5 | Sea Gull walkway | 8214.5 | 5.11 | 27° 43.80' 097° 07.90' |
| 6 | Private House walkway | 9676.7 | 6.01 | 27° 43.06' 097° 08.40' |
| City of Corpus Christi | | | | |
| 7 | Various datums | 11270.3 | 7.00 | 27° 42.37' 097° 08.86' |
| - | Apron of Access Road #2 | 11812.3 | 7.34 | 27° 42.11' 097° 09.03' |

various markers and sign posts to locate the beach width sites until they were removed, destroyed, or vandalized. When this happened I relocated my sites as close to the original as possible. Often, I could foresee that a marker was about to disappear and measured the lateral distance between it and the next potential datum prior to the original's destruction. In some cases the post unexpectedly disappeared and I was usually able to estimate the location of the original in respect to the new one.

### 3.1. Vehicles on the beach

Vehicle access is unlimited along the BEACHobs study transect. When the survey started the only way the public could get to the beach was by automobile, entering and leaving at either access road. Many vehicles traversed the length of the beach in both directions. The Texas Open Beaches Act (http://www.glo.state.tx/coastal.html) allows public access to the beach including via automobile. The Texas Department of Transportation designates the beach as a highway with all traffic laws in force. Driving lanes get established on the sand, usually on the backbeach close to the dune line. Driving is prohibited within 50 ft of the water, but beach conditions regulate the location of the driving lane(s). The effect that driving on the beach has on the dunes and the results of this study are manifold, but essentially, driving prevents the formation of coppice dunes during the summer that would otherwise extend the dune line seaward. To maintain the driving lanes and prevent vehicles from getting stuck in the sand, the various authorities use heavy equipment, especially road graders. This has the effect of building a sand ridge close to the dunes and often to remove the undulating toe of the dunes where tendrils of vegetation (especially goat's foot morning glory) encroach onto the beach as part of the dune-building process.

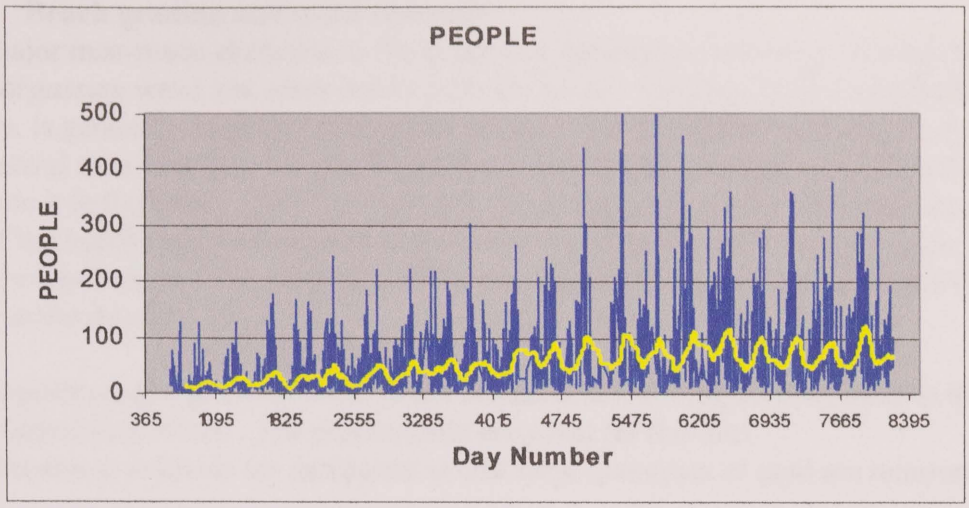
### 3.2 Development of the beachfront

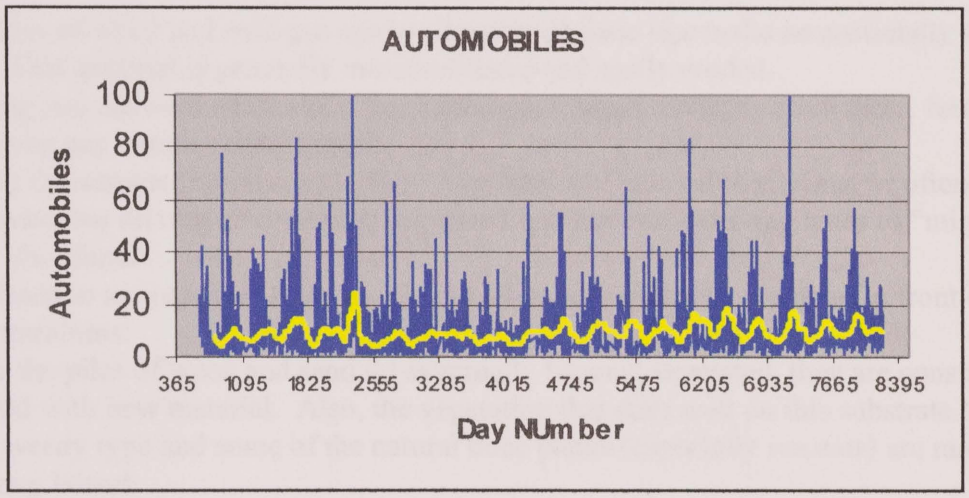
There was no beachfront development between the access roads when this survey started. At this writing there are 14 condominiums, several Private Houses, a residential development, and a large R/V park, all with beach access over or through the dunes (Table 5). An interesting development in vehicle use on the beach has occurred since the beachfront condominiums became popular among the beach-going public. The ratio of people to vehicles has changed from an average of 2:1 to about 5:1, indicating that more people are utilizing the condominiums to access the beach than are using automobiles (Fig. 5).

Table 5. Location of man-made structures with beach access on Mustang Island Gulf beach in the BEACHobs study area as of June 2000. Distances are miles from Access Road #1. See Appendix I for location of all beach structures and how they have changed with time, and Figure 26 for their present locations.

| STRUCTURE | DISTANCE |
|---|---|
| Pioneer R/V Park | 1.07 |
| Walkway | 1.42 |
| Beach Walk 1 | 1.53 |
| Beach Walk 2 | 1.58 |
| Casadel/El Cortez | 1.77 |
| La Mirage | 3.64 |
| Mariner's Watch | 3.71 |
| Gulf Shores | 3.76 |
| Mustang Towers | 3.93 |
| Mustang Beach Club | 4.17 |

| STRUCTURE | DISTANCE |
|---|---|
| Port Royal | 4.27 |
| Sea Gull | 4.92 |
| Sandpiper | 5.11 |
| Lost Colony | 5.34 |
| Religious Retreat | 5.54 |
| Hawn House | 5.70 |
| Private Houses | 6.04 |
| Admiral's Row | 6.27 |
| Mayan Princess | 6.40 |



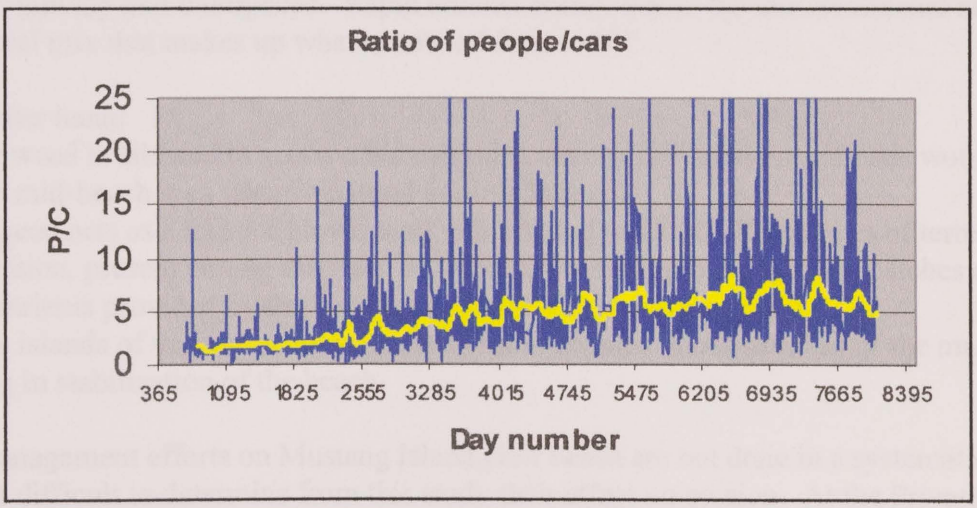




Figure 5. Human activity on Mustang I. Gulf beach. Top: Number of people on beach at time of survey. Middle: Number of automobiles. Bottom: Ratio of people to automobiles.

### 3.3 Beach grading and weed removal

The major man-made alteration to the beach and the dunes is the effort to grade the beach and remove *Sargassum* weed and other debris from the beach. Grading, using road grading machinery, is generally used to maintain driving lanes and the apron ways at each access road. Weed removal uses front-end loaders, beach rakes and trucks to scrape the weed off the beach and relocate it in the dunes. This is done more frequently opposite the condominiums than along the rest of the beach, but recently almost the entire length of the study beach has the weed removed in this fashion. The main effect of these operations is to redistribute sand from the shoreline to the dunes.

It is my hypothesis that grading, weed removal, and beach driving all contribute to the erosion of Mustang Island Gulf beach. The mechanisms proposed for this are:

- Weed removal methods are inefficient in that large quantities of sand are removed with the weed.
- The piles of weed and sand put against the natural dune line make an artificially steep dune face. This material is generally unconsolidated and easily eroded.
- Grading just seaward of the dune line encourages beach traffic to drive there, further inhibiting any coppice dune growth.
- During the summer months, especially June and July, rainfall is minimal or often nonexistent. A treacherous driving environment is created and forces the driving lanes to "migrate" closer to the shoreline.
- This leads to an increased effort to remove the weed in places other than in front of the condominiums.
- While the piles of weed and sand do eventually become vegetated, they are constantly being covered with new material. Also, the vegetation that does well on this substrate tends to be a more weedy type and some of the natural dune plants (especially sea oats) are rare now on Mustang Island.
- Without coppice dunes, and with a generally low profile beach, storm tides reach the main dunes quickly and unimpeded. Rapid erosion ensues due to the unconsolidated nature of the material mix that makes up what is now a "dune wall."

On the other hand:

- If the weed is allowed to accumulate naturally, successive summertime tides would push it up to the mid-beach area where a natural berm is formed.
- The weed acts as a trap for blown sand, minimizing saltation. Propagules of terrestrial vegetation, present among the weed or windblown, form pioneer growth patches enhanced by the nutrients provided by the decomposition of the *Sargassum* weed.
- These islands of vegetation develop further into coppice dunes seaward of the main dune line, aiding in stabilization of the beach.

Beach management efforts on Mustang Island Gulf beach are not done in a systematic way, making it difficult to determine from this study their effect on erosion. At the Private Houses (Mile 6), the residents requested that Nueces County not clean the weed from the beach in front of their property. This did not provide a definitive test because it was a very narrow area (maybe

100 m of beach), and the county often "forgot" the special request. What was needed was a more extensive beach with no beach traffic and no beach management. In 1995, we started a survey on the privately-owned San Jose Island that provided such a contrast.

## 4. EVENTS THAT SHAPED MUSTANG ISLAND GULF BEACH, 1979-2000

The following annual descriptions are brief excerpts (more detailed with major events) from the BEACHobs notes on weather and other events that have affected beach and the methods of measuring the beach. Refer to Figures 11-23 and 26-53 to see the effects on dunes and shoreline. Note that the annual Gulf Shores plots (Figs. 11-18) do not show the incursions of the sea to the dune line unless that occurred at the time of observation (no high tide line is shown on these figures to avoid confusion). Gulf Shores high tide lines are shown in Figures 19-23.

### 4.1 1979

Tar from the IXTOC I oil platform blowout washed ashore in huge quantities in August and September of 1979. A commercial company was hired to cleanup large tar reefs that formed in the troughs between sand bars. They had to complete the job by December 31 but left many intact. These remained in the environment for at least eight years. The cleanup effort required piling huge quantities of oiled sand temporarily in the dunes. Several powerful storms fulfilled the unfortunate statement from Austin that all that was needed to get rid of the tar was a hurricane. **Hurricane Amelia** did remove the tar but put it back on the beach. BEACHobs #62 had to be abandoned on September 13, "*have to abandon or get washed out to sea.*" On September 16 dunes were eroded, and again on September 20 when all beach signs were washed away and the dunes were eroded back forming "*2-m high cliffs.*" It was these events and the IXTOC oil that prompted me to start measuring beach widths.

### 4.2 1980

On January 9 it was announced that the Burmah Agate tanker fire was "*under control*" and tar from that spill off Galveston was being transported south to our beaches. Tar from this spill and especially from IXTOC were a daily feature of the beach at the start of 1980. A slow-moving front on January 22 narrowed the beach and made driving difficult on soft sand. Rough seas broke through the berm on February 7 and a narrow, rough beach again made driving difficult. On March 5 tides came up close to the dunes. The IXTOC I well was finally capped on March ??. New coppice dunes started forming near the Access Road #2 blowout area. This active dune region was often characterized by blowing sand, as on April 13, when the phenomenum was described as "*incredible.*" In May large quantities of *Sargassum* weed and tar covered the beach. A high tide on May 14 forced me to "*drive in the sea,*" and on May 16 the tide reached the dunes. On May 19 the beach was at its narrowest, destroying several overnight camps.

A **tropical depression** went ashore on July 7, pushing the tide near the dunes. On July 19 Gulf Shores "*bulldozed the beach clean of weed, tarballs, and sand.*" The defining event of this study occurred on August 9, 1980, when **Hurricane Allen** went ashore in Kleberg County. Figure 6 shows the study beach from high-altitude imagery taken a few days following Allen. I left the


Figure 6. High altitude imagery of Mustang Island Gulf Beach survey site (between the two access roads). Yellow triangles mark location of the measurement locations done at one-mile intervals, starting at Access Road #1. The special site at Gulf Shores condominium is also indicated. At the time the image was taken, only three condominiums were built on the survey beach: El Cortez, between Miles 1 and 2, Gulf Shores, and Lost Colony between Miles 5 and 6. Prominent dune washout zones are near Access Road #2, and between Miles 4 and 5.

island for higher ground on August 8 and was able to return on August 11. These are notes made then. "*Beach totally changed. There is a fence running along the beach about 30-m from face present of dunes. This is apparently where the old dune line was. So there has been 30-m or more of dune erosion (actual measurement 26 paces). As soon as I arrived at Access Road #1, I was met by Susan Noyes of radio station KOUL, who leapt in the car and started asking me questions re. the erosion, etc. Ocean rough - many lines of surf - grey color plus yellow-brown spume - tons of it. The Grace Methodist bus group of campers did not get all their vehicles away, three cars left totally buried in sand. Two old men were there who were former residents of the camp. One, Gordon Cahill, said that all his possessions were buried with his car including some mementos his mother gave him that were 140 years old* [he never got them back, the county dug the cars up and bulldozed them into the dunes]. *He barely escaped with his life and had to abandon his bedroll, etc. on the dunes to avoid getting drowned. At Mile 1.92, a Civil War wreck is exposed - iron spikes and wooden spars sticking out of the sand (photos). I must have driven over this many times* [several rare birds were found but are not pertinent to this report]. *Gulf Shores now looks like a box sitting on the sand. You can see underneath the building and look at the foundations* [see Cover photos]. *All structures in front of hotel* [sic] *are gone, road signs, walkways, and dunes. Lost Colony Condos - considerable erosion and undercutting of leading units (photos). Can now look up and see concrete base foundation and 'cheapo' construction. Pipes and electrical conduits hanging all over the place. Other pilings now exposed at mile 6.01, 3 broken pilings 53 m from present dunes. At one location, dunes have a tar stratum, 20 cm below top of dunes, 1.9 m above present beach level. Tar is hard and thin, not smelly. Miss Olimpia* [wreck] *still visible at mile 6.45. At mile 7.06 a second line of pilings occur* [I think these might have been an old dune line fence]. *Northernmost Gas and Electric line warning sign destroyed, 2nd intact but no longer standing in dunes. Access Road #2 pavement destroyed. Now difficult to find the road. Big chunks of re-worked IXTOC oil at washover channel* [see Fig. 6] - *shiny liquid center when broken.* A **tropical depression** went ashore near Houston (8-13 inches of rain) on September 8 but had little effect on the wide beach formed here.

By September 27, the vehicles were driving between the old dune line fence and the dunes. The first cold front of the season came through on October 22. Another on October 27 had 30-kt winds and "*all beach features were rapidly becoming obscured by blowing sand.*" The tide pushed to the dune line in places. **Tropical Storm Jean** swept the beach clean and the tide went up nearly to Gulf Shores wall again. The tide came up to the old dune line on November 25. I noted during this strong norther that "*Rain comes in car - need internal wipers. The wind almost removed car door when I opened it. Wind gust blew cup off my anemometer.*" By December 5, a berm was forming at the shoreline.

### 4.3 1981

No measurements were made between early January and April 1. A late cold front on May 10 swept the beach clean and pushed water up to the dunes but did not erode them. A **tropical depression** 75 miles east of Corpus Christi caused considerable beach and dune erosion on June 5. This had the effect of arresting post-Allen dune growth and forced drivers to use the newly revegetated areas, furthering the destruction of the coppice dunes. Another storm produced

similar conditions on June 15. There was little tropical storm activity in the Gulf this year (only **Danny** on west coast of Florida, September 5, and a disturbance in Gulf of Campeche, September 29).

The first norther came through on September 19. On October 8 a large quantity of driftwood came ashore and was later put on the dunes. A substantial summertime berm formed this year but was frequently cut by channels in the fall. In November and December there were periods of extra wide beaches. I was able to walk around the wreck of Miss Olimpia. By late December much erosion of the beach had taken place and on the last day of the year, the sea came up to the dunes.

### 4.4 1982

No measurements were made between early January and February 21. High tides on March 30 were actively eroding new dune vegetation. On April 4 major construction of an offshore pipeline began near Mile 4. The dunes were tunneled by horizontal drilling and pipe was temporarily placed for several hundred yards along the dune line. High tides disrupted Easter beach traffic on April 10. The pipe was towed out to sea on April 17. No measurements made between April 24 and May 10. High tides on May 13 forced drivers landward of the growing dunes. A dune restoration project was in progress at the Hawn House walkway. On August 8 the beach was graded with a road grader. A new technique for beach management here?

A **tropical depression** in the Gulf did little to raise sea level here but did damage in Galveston area. High tides on August 22. A **tropical depression** 200 miles S of Houston and 200 miles east of Brownsville caused high tides here. No dune erosion. There was "*No beach*" on October 1 due to tides. A walkway was built over the newly-restored dunes at the Hawn House.

On November 4 tides went beyond old dune line and on November 14 a walkway was built over dunes at Mustang Towers. On November 24, a strong norther built transverse dunes of blown sand on the backbeach. The First BEACHobs vehicle (Peugeot 504 Diesel) died when a tie rod rusted through. On November 30 a new Toyota 4WD truck was put into service for BEACHobs. Very high tides occurred on Christmas Day and much beach erosion followed.

### 4.5 1983

From January through April there were several instances of high tides forcing driving landward of the pre-Allen dune line (e.g., January 19). On January 21 dune erosion occurred, water came up to the Gulf Shores fence and the cars buried by Allen two-plus years ago were partially exposed. Several outcroppings of Houston clay were exposed at the shoreline. A high pressure gas line was exposed on the beach at Mile 6.65. In February low tides exposed many IXTOC tar reefs. The buried cars were dug up and pushed to the dunes on March 12. No chance of finding the old man's mementos. A short-lived (illegal) barbed-wire fence was erected along the Flato property at mile 2.42. A walkway was built over the dunes at Admiral's Row (mile 6.21). Very high tides occurred on May 13 and on July 14. On August 23 I did a 27-hour time series BEACHobs (nine surveys at 3-hour intervals).

All driving lanes were washed away by rain (7.5") on November 10. November saw an early Arctic cold front with very strong winds. On November 27, I started measuring beach widths at mile intervals. At one time the beach was covered with tumbleweed from the coastal prairie. The late winter of 1983 experienced one of the coldest air temperatures on record. There was frozen spume at the shoreline on December 25 and an air temperature of 16.7F (-8.5C). Due a bout of bronchitis I was only able to measure at Gulf Shores after mid-December.

### 4.6 1984

I embarked on a daily observation schedule in 1984 to test the statistical viability of the observation frequency. The seven-day gap in January was due to a complete loss of the log sheets for that week. The HP computer was initiated in 1984. It took weeks to perfect the program and as a consequence some of the notes are sparse. A powerful norther in late February created both very high and very low tides, exposing the wreck of the shrimp boat Brant at mile 2.02. Tides encroached on the dunes. On April 4 the Gulf shrimpboat Little Richard ran hard aground at mile 2.03. It was pulled off a few days later. On April 24 a walkway was constructed for Mayan Princess (mile 6.4). This spring saw the start of removing *Sargassum* weed from the beach in front of the condominiums. The usual spring storms continued until May giving a spiky appearance to the record. A powerful norther occurred on May 8, blowing sand from dunes to beach. The 80 ft wooden Gulf shrimp boat Miss Chachita was wrecked and totally destroyed at mile 1.61. On May 23 the Miss Chachita wreckage was put in the dunes. By June 6 vegetation had started to establish itself on the mid-beach area. The beach became so rough and dry that numerous vehicles got stuck in the sand this summer.

The Alvinas oil spill oiled beaches in Galveston in early July. Vandals destroyed my Mile 4 and 7 posts in late July. Strong onshore winds on September 2, an early norther on September 4, followed by a another on September 21, caused considerable dune erosion (seen in Fig.12 as a reduction in the beach width). The "*worst rainstorm in memory*" in extreme South Texas; storm 75 miles east of Brownsville, but it is "*not tropical - strong swell here.*" I made three beach profiles with John Snedden from LSU in October. On November 9 two oil-rig legs washed ashore (miles 2.39 and 6.65). A third came ashore at mile 6.11 the next day.

The 1000$^{th}$ BEACHobs survey was done on December 1. On December 8, crews removed the three massive steel legs from a jackup rig destroyed in a storm. This was done by jetting a vessel on to the beach and creating a lagoon the enabled the legs to be towed to sea. This left large indentations in the shoreline that became isolated pools and by December 13 could hardly be discerned. There were two periods in December when the beach was very wide following northers.

### 4.7 1985

I continued daily observations in the first part of January to compensate for the lost days of January 1984. Some periods when the beach was extra wide occurred in January. The most powerful front on January 20 brought freezing temperatures of 27.8F (-4.2C) and 30-kt winds and exceptionally wide beaches. No surveys were made between mid-January and mid-February and again in mid-March. Hundreds of trees and lumber washed ashore on March 3. The spring

and early summer were generally uneventful, but on several occasions in late summer and fall, tides reached the dunes and beyond.

On July 16, tide "*penetrated 30-m into dunes*" at the washover zone at mile 7.1. A major oiling of the beach took place in July. On August 6, one of the first attempts to remove the *Sargassum* weed was made using a home made rake towed by an old blue car. No surveys conducted between late September and mid-October. **Hurricane Danny**'s storm surge eroded 10-m of dunes on August 16, but **Hurricane Elena**, that went ashore in Mississippi on September 3, had little effect on Mustang Island Gulf beach. A norther on September 15 pushed the sea up to the dunes. That was followed by a tropical wave two days later that also brought the sea the dunes. **Tropical Storm/Hurricane Juan** in late October eroded the dunes and destroyed mid-beach vegetation and incipient coppice dunes, hence the wider beach for several days. A late **hurricane (Kate)** pushed seas up to the dunes in mid-November. With several condominiums now in place, the *Sargassum* weed was regularly cleaned using beach rakes in front of each condo. Beach grading became more commonly practiced in places now.

### 4.8 1986

Several cold fronts affected the beach in January and February. On January 11, the beach was "*planed flat*" by high tides that washed away "*extensive dunes that had formed on the mid-beach.*" Much dune erosion occurred at the Mustang Towers walkway on February 10 (mile 4.02). The beach became exceptionally rough in April and May and *Sargassum* weed came ashore daily, creating public demand that it be removed. Late northers came through on April 15 and May 17 with 40-kt winds. The effects of these events can best be seen at Mile 0 where the beach is depressed due to road maintenance.

**Hurricane Bonnie** went ashore near Port Arthur, Texas in late June but had little effect on Mustang Island beach, neither did tropical disturbances in early July and August. By late June, the backbeach became difficult to drive on and the driving lane shifted closer to the shoreline. A Gulf shrimpboat, Diamond Clipper, went aground near Mile 2 on July 4. It was pulled off two days later. Dead palm trees were piled in dunes at mile 4.4. A horse-riding business started up just south of Access Road #2 in July. Groups of horses head north in study area a couple of miles, damaging the beach surface (later they were restricted to a mile south of the access road). In late September, tides began to reach the newly-formed mid-beach vegetation.

An outbreak of red tide in September and October killed millions of fish. Had to do surveys wearing surgical mask. Heavy equipment was used to pile dead fish along the dunes. Survey vehicle gets several tire punctures due to fish bones on beach. Several days of strong southeasterly winds combined with October's normally high tides pushed water on the midbeach and created a ridge and runnel formation. Later Nueces County trenched the beach to bury dead fish. No surveys were conducted after November 27.

### 4.9 1987

No observations were made in 1987 until February 14. In early March storm tides pushed up to the dune line destroying mid-beach vegetation that had formed in 1986. Low tides in March

exposed debris and tarball reefs (again in mid-April), but the truck was "awash" on March 17 as dunes were eroded. On March 29 a powerful front dropped temperatures to 44F (6.9C). On April 9 I started a separate survey to count marine debris for a study on MARPOL Annex V. In all, 189 surveys were made along the BEACHobs survey transect between 1987 and 1992 (Amos, 1993). Tides reached the dunes in late May and mid-June. Mid-beach vegetation "doing well" in June.

In late July piles of wood were pushed up to dunes along length of beach. High tides and big swells due to a **tropical depression** off Galveston caused no erosion here (August 10). County uses prisoners to hand-remove beach debris. Workmen removed dunes from around Private Houses walkway (my Mile 6). Conditions were quite stable throughout much of 1987. In mid-November the sea came up to the newly-formed coppice dunes. Very low tide on December 4. The "*ribs of Brant*" well-exposed. No surveys were done between December 20-30.

### 4.10 1988

High tides of February 6 pushed beyond the coppice dunes. They *"survived, but are surrounded by water*". By February 8 the driving lane was landward of the coppice dunes and that "*doesn't bode well for their survival*". Blowing sand on February 24. On March 7 I noted that the dunes in the wash-over zone near Access Road #2 have "*built up nicely over the years*". Driftwood pushed up into dunes. Tenth anniversary of BEACHobs on April 14. A Kemp's Ridley turtle nested at mile 5.83 on April 26. First for 25 years. On April 30 a strong storm pushed water up to the fence line at Gulf Shores (and over the turtle nest site); 62-knot winds in Port Aransas. I noted "*there is no beach now!*" Two more events in June brought the sea to the dunes but no erosion.

No surveys were done between July 21 and September 13, just in time for **Hurricane Gilbert**. Tides were high on September 15 and I just managed to get off the beach and complete the survey. The last half-mile I drove in the sea. Gilbert went ashore south of Brownsville. Mustang Island was evacuated and I managed to get back on September 17. Here are extracts from my notes on that day: *"Post Hurricane Gilbert obs; dunes eroded back 17.5 m from my dune line posts; more pronounced by Access Rd #1; also dune erosion parallel to my D/L posts. Heavy dune erosion looking N-S (mile 0.6). Old car chassis uncovered; was this the "old Man's car?"; where are his mementos? Spume blowing ashore across the beach. Much spume as with H. Allen. Almost no garbage on beach but a lot in the dunes. Many morning glory roots; also tons of brown water-hyacinth stems, leaves & roots. Old dune line eroded at least 5 m at Mile 1. Will use the big post in the dunes as a new datum here; 34 m landward of old datum? Now I must use an "immovable" datum and also record the recovery of the dunes. New D/L is 7.7 m from S/L. Considerable erosion at El Cortez; walkway exposed for 25.6 m. Civil war wreck is now completely out of the dunes (i.e. dunes have been eroded away behind the wreck by 9.7 m). I am driving where two days ago there were dunes; otherwise there would be no beach New D/L; 15.3; new datum(sign) 12.1 at Mile 2. Garbage blown over the top of dunes. Both signs down; no "permanent" datum here (Mile 3) Most of new dunes in front of Gulf Shores gone. Tide up to grass; not as bad as H. Allen; no wind damage. Cannot find Mile 4 post; may not even be at Mile 4. There has been 14.6 m of dune erosion here (Mile 5).* [Face of ] *dunes 1.4 m high. All*

*new dunes gone at Private Houses (Mile 6). Once again all reference posts gone (Mile 7);* [Nueces County] *Mile 12 sign gone; post survived.*"

After this (on September 27) I measured to the dune line as well as the datum posts (they had to be re-defined in some locations). Once again, it appeared that the beach sand had been replenished from a near-miss hurricane. Tides came up to old dune line again on October 8 but also "*much sand has accumulated landward of old dune line but not formed into dunes*". New dunes formed in front of Gulf Shores on November 5. On November 10 much of the new dune sand had been blown away by north winds, but was blown back two days later by strong southeasterly winds, and I remarked that "*almost all the dunes have been rebuilt since Gilbert.*" This process repeated several times in the next months. **Tropical Storm Keith** may have been responsible for high tides on November 24. On December 22 the City(?) and Nueces County "*scarfed the toe of the dunes and piled sand up at the shoreline. Why?*"

### 4.11 1989

My travel in 1989 was extensive and there were many gaps in the data: January 15-23, March 13-25, March 31-April 9, May 27-June 8, August 21-September 3, and September 18-December 10. A very wide beach on February 4 was due to a strong norther and rare freeze. The cold weather lasted for days with accompanying sea smoke due to Gulf water warmer than the air. With a near-freeze on March 6, the beach was even wider (nearly 100 m [317 ft] at Gulf Shores). A massive quantity of *Sargassum* weed came ashore in the spring and summer of 1989. By mid-June the County Commissioner had requested State aid in "cleaning" the beach. A large-scale grading effort continued for weeks and I believe this was the beginning of annual weed-removal operations using heavy equipment. The weed needed cleaning "to save the multi-million dollar tourist industry." In late June weed and sand piles were being dumped behind a snow fence at Lost Colony.

An unusual event was the movement of **Hurricane Cosme**, a Pacific storm that crossed Mexico into the Gulf of Mexico. On June 26 it redeveloped as **Tropical Storm Allison**, centered 150 miles southeast of Corpus Christi, and pushed the tide up to the dunes, spreading weed from shoreline to dune line, negating all weed removal efforts. The mid-beach vegetation was "*battered but still hanging in there.*" The remnants of Allison returned south and tides stayed high. Sixty shrimp boats blockaded the Aransas Pass on August 24 to protest the use of Turtle Excluder Devices (TEDs). On August 1 **Hurricane Chantal** went ashore at High Island, Texas, the storm surge pushed tides to the dunes and created a "risky driving" day doing BEAChobs. By August 19 the weed/sand piles dumped in the dunes were starting to get vegetated. In December there were unvegetated coppice dunes and vegetated dunes seaward of my datum posts, rebuilding since Gilbert and with help from *Sargassum* cleanup.

A near freeze on December 12, during a norther that created extra wide beaches, was followed by a freeze on December 16. On December 23 the coldest weather in recent memory followed the passage of an Arctic front. Some excerpts from my notes: "***89/12/2*** *Arctic cold front; high winds; bitter cold. Blowing sand obscuring HT/L, guessed where it was; Wet Bulb-6.5, Dry Bulb -4.3 (24.3F), Sea Temperature 5.7 (42.3F); overcast; to say "cold" would be understatement.*

*Interesting sasturgi-like sand structure on backbeach; frozen substrate stripped of soft sand by wind. Tops of waves being whipped away by winds; photos. Only one bird* [and one person] *actually on beach.* ***89/12/23*** *- Large dead red drum; the start of the fish kill? Frozen cabbageheads; pure white; photos. Probably the coldest day on record in P.A.! 12.3(F) at the lab when I left; ice and slushy footprints at shoreline. Crescent-shaped dune formation (what is the correct name for those?)* [Barchan dunes]. *Measuring wheel picking up slush & sand and then the whole lot freezes making its diameter too large. Sea temperature a record 1.2C - 35F!. To verify, I went back in with psychrometer (1.5C); my cost? –a boot full of 1.2 degree water plus a hat blown into sea (recovered). Wet Bulb-10.0; Dry Bulb -9.6 (14.7F); Sea Temperature 1.2 (34.1F); Wind 22 kts from 000. Clear, sunny, beautiful but arctic cold! Post seaward of S/L topped with ice. Frozen clam at S/L, foot extended. Dead fish encased in ice; porgy? Dead quahog-type clam; foot extended. Dead fish encased in ice. An ice-covered Miss Olimpia. Strange formation at S/L; islands of frozen sand. Stratum of frozen sand atop loose sand; broken up into pieces."* 1989 was also a severe drought year. Port Aransas received only 19.55 inches of rain (mean annual rainfall 1985-1999 is 34.22 inches).

**4.12 1990**

No surveys done until February 7. I pondered whether my measuring to newly formed but low dunes was correct and on February 15 reverted to measuring to where the major vegetated dunes begin. The change in dune location in the figures is artificial. Very wide beach on February 25. In mid-March the sea almost reached the dunes. On March 30 a front hit while I was doing the survey and I could observe the sea recede as north winds lowered sea level at the coast. A cold front in early May pushed water to the dunes. On May 23 I decided to cut down the BEACHobs frequency to every fourth day because of work pressure. It didn't last long; by June 18 I was back on a bi-daily schedule. On June 3 the Gulf Shores walkway was dismantled and a new one built, extending farther seaward over the growing dunes. Two large driftwood trees were placed on the Private Houses dunes to promote growth (Mile 6). Within days, dunes formed seaward of the logs. At Mile 6 on July 22 one of the old posts exposed after Hurricane Allen was removed as a hazard to bathers.

No surveys were made between July 26 and August 8. High tides due to **Hurricane Diana** (went in to Mexico) on that day, eroding dunes, and dislodging the trees put on dunes at Private Houses. It was a quiet storm season locally and dunes had built "*so high at Private Houses that it was difficult for me to see my datum post*" there. Some notes from October 4 illustrate typical beach processes: *"Recent strong SE winds have stripped sand from beach creating very rough surface and horrible driving. Last obs the landward half of the beach was covered with soft sand, now it is stripped to the hard substrate; quite dramatic! The exact reverse conditions opposite Gulf Shores; soft sand still on landward half of beach; obviously an effect of the condo. This is the reverse of what I had thought; that the condo would (and has) inhibit dune growth here. Maybe the dunes closer to the condo are inhibited. People stop & tell me I have a cushy job 'punching in that little machine!' (if only they knew)."*

On October 18 a typical strong norther came through during the survey with blowing sand obscuring all marks, making it difficult to decide the location of the high tide line. Also,

"*Miniature sand dunes forming inside the Toyota as sand enters through every crack and into the Toyota cab. The sun shines; the wind blows; the air dries; beautiful. One of the more absurd BEACHobs events; I am halfway across the beach measuring its width when I see the Toyota trying to self-destruct, rolling rapidly into the sea; blown along by 30-kt winds, joining the bouncing bottles, flying floats and cartwheeling cans. Computer and surveyor's wheel in hand, I run after the truck and leap into driver's seat, diverting the truck's suicide just as it is heading out to the second sandbar!*" The beach was wide in early November and a storm late in the month pushed the sea to the dunes and strong onshore winds produced soft transverse ridges over older, harder longitudinal ones and scalloped wet indentations created by high tides. Christmas trees were put in dunes even before Christmas.

**4.13 1991**

No surveys were done between January 2-February 16, April 10-May 16 (in 14 years of doing BEACHobs, this was the first spring missed), July 7-25, October 31-November 16, and November 24 to the end of the year. On March 11 the Toyota truck did its last BEACHobs, 8-plus years and 81,532 miles after doing the first. A new Toyota 4WD truck went into service on March 13. A cellular phone was another technical innovation used for the first time the same day. I noted at Mile 7 that "*all the beautiful barchan dunes had been destroyed by off road vehicles.*" The spring was a period of dune growth with one big event on March 17 with minor dune erosion, and on May 23, I noted: "*A **disturbance** in Gulf has produced high tides. Seas coming up beyond dune line (even as I write this). Toyota truck almost in the sea. Oh the futility of man's efforts compared to nature. All those bulldozers & weed-cleaning crews - and now the weed is totally redistributed. Sea well landward of Gulf Shores walkway. Tide still coming up; driving in water most of time* [Not good for new truck]. *Big surge today; essentially there is no beach.*" In early June money began washing in with the *Sargassum* weed. This happens most years and locals go looking for it. I found a $1 bill but others found hundreds. Two more events caused minor dune erosion in June. The last event was "*one of the most powerful storms of BEACHobs*" with seas threatening to cut me off several times.

From July 22 on, an oil spill coated the beach with tar. The spill was of unknown origin but crews were sent to clean the beach. Coincidental with this, a new mechanical beach rake was used to remove weed (and designed to remove little else) by Nueces County (it is called the Barbour Surf Rake and cost $80,000). Prior to this, agricultural-type rakes were used, towed by tractors. On September 5 the County employed three trucks, a front-end loader, the beach rake, and a cage truck in a major assault on debris and litter in front of the condominiums. On September 19 I retired the HP75C for an HP75D (larger memory; 64K instead of 24K). On September 27 my Mile 1 marker disappeared without a trace. I was able to see where I had measured on the previous obs and able to find a new post north of the old and 2-m seaward.. The Civil War wreck was now almost completely buried by advancing dunes.

A storm on October 7 penetrated beyond the main dune line and eroded some of the mid-beach vegetation that had become established. The morning glory began to die a week later. The Gulf Shrimpboat Li'l Justin ran aground on November 18. Salvage crews dug a basin around it and tried to pull it off with another shrimp boat. The boat was eventually salvaged. No surveys were done after November 24.

### 4.14 1992

There were several lengthy gaps in the survey in 1992. None were done until January 19 and I was on lengthy research cruise from February 12-May 5, July 5-August 25, October 27-November 26, and November 28-December 6. No other year during the 21-year survey has so many gaps.

Truckloads of Christmas trees were brought to the dunes in late January. On January 27 the 2000th BEACHobs survey was made. Metal posts at the shoreline exposed by Hurricane Allen were still visible and at Mile 4 I measured their location for future reference. The wide beach of January 29 was quickly replaced by narrow beaches in early February. On returning in May I found Mile 3 marker had been moved, but the old post left in place. For the first time, dunes had advanced seaward of my Mile 7 marker. As grading of the beach in front of Gulf Shores seemed now to be a permanent operation, I attempted to add "graded region" to my measurements there. I did the survey on July 7 using a GPS, but found that the Selective Availability (SA) errors were too great for it to be used as a meaningful survey tool.

I returned to the survey on August 25 along with Hurricane Andrew, now off Louisiana after devastating Florida. The next day Andrew went ashore at Morgan City, causing the tide here to penetrate the dunes. A Gulf **disturbance** of unknown origin caused considerable dune erosion in the first few days of October. I remarked *"Tides are very high. Almost as high as I have seen. The dunes are being eroded away considerably. The high tides have re-exposed my old Mile 3 post. It is 8.0 m seaward of my new Mile 3. Much erosion of dune vegetation. This will set back dune growth for years. Erosion of morning glory."* Heavy seas and high tides pushed water up to the dunes again on October 23. The beach was eroded by this event, exposing long-buried metal posts at the shoreline. This year there were several instances of the beach being raked or scraped even when there was no debris of any kind to remove. 1992 saw a record rainfall total of 51.04 inches.

### 4.15 1993

No surveys were done from January 5-February 14, May 16-28, July 28-September 16, October 22-November 7, and after December 20. The cold front February 26 brought tides up near the dunes but the beach widened considerably in early March. On March 2 I started using a GPS to test its utility on the survey. I routinely recorded the GPS position at each of the Mile posts. Widespread prediction in the media that March 8 would bring the "Great Perigean Tide" (Full Moon + Moon nearest Earth) was unfounded (our tidal cycle is controlled by the Moon's declension rather than its phase). Grading the beach started on March 20 to remove the large quantity of *Sargassum* weed. On April 23 I noted that the bulldozer was pushing piles of weed and sand into the dunes, building thenm up and also "*substantial dune-building [naturally] under strong onshore winds.*" On May 6 I noted that the beach has been planed flat by yesterdays storms in places where the beach has been cleaned, but elsewhere the "*weed has held up and sand has not been lost.*" Later that month at the invitation of a condominium resident who was appalled by the beach-cleaning using heavy equipment, I got an interesting perspective from the 10th floor of Sandpiper condominium.

At the start of the tropical storm season in June, the mid-beach vegetation had become well-established but ended abruptly where beach cleaning had occurred. **Tropical Storm Arlene** caused dune and beach erosion on June 20: "*Tropical storm Arlene went ashore near Baffin Bay earlier this morning. A late but viable obs. There was no way I could do the obs earlier. High tide was at 0630. There was no beach (there is not much now!). The tide is coming up to the dunes frequently inundating the truck. Video. All the weed has been pushed up the dunes here. Video. Rain showers in bands coming ashore. Tide has come up beyond the Gulf Shores walkway. There has been dune erosion here (Mile 4). Piles of weed, sand, and garbage are being eroded. I am still driving mostly in the sea! In general the dunes have been significantly eroded, primarily the new coppice dunes. Except for city limits did not notice big difference between clean ed and non-cleaned areas as far as erosion . The sea was up to the dunes all along anyway. May see better next obs. The tide stayed up for two days and is still up. This was longer, not higher, than any time before.*" Two days later: "*The storm has eroded the dunes here. The Mile 1 post is now much more accessible. Before it was getting difficult to measure with the wheel due to vegetation growth. Already the inundated vegetation is beginning to turn yellow and is dying.*" The tides from **Hurricane Gert**, that went ashore near Tampico on September 20, had planed the beach flat when I returned on September 24. On the 20th the tide came up nearly to the dunes.

I abandoned the use of the GPS on BEACHobs on November 10. In early November the tide went up to the dunes for several days and there was erosion of the berm. On November 26, an Arctic front brought near-freezing air temperatures and a wide beach. On December 14 there was an exceptionally wide beach when the night before, water had been up to the dunes.

### 4.16 1994

No surveys were made between January 7-February 13, March 26-April 3, May 23-June 19, July 28-August 9, October 4-15, and after November 17. On January 5 the City of Port Aransas moved its city limits to mile 3.67, just north of Gulf Shores. They also started putting pilings in at 1/10 mile intervals from Access Road #1 to the new city limits. On returning to the survey on February 13, I adopted certain of these posts for mile marker datum posts (see Appendix I). When the posts were put in they were just landward of the then dune line. On February 28 new signs were put on the mid-beach delineating an area where parking was allowed free of charge. This area is used by campers who can overnight there without paying fees. The area stretches from Markers 52 to 58 (0.6 miles). The wide beaches of early March exposed some of the old metal posts at the shoreline. High winds on March 10 stripped away the soft sand leaving a hard, shelly substrate. Dunes had built up in front of the private house walkways which are now 10 m behind the dune front. The tide encroached on the dunes and rough seas eroded the shoreline during April. The manicuring of the beach in front of the condos using the beach rake is now a daily operation and may be affecting my measurements at Gulf Shores. Minor dune erosion occurred at the end of April and the beginning of May.

**Tropical Storm Alvarado**, heading towards Louisiana on July 2, had no effect on Mustang Island beach, and the storm season was quiet until mid-September when the remnants of **Tropical Storm Debbie** pushed water up to the dunes and beyond for a few hours. Mid-beach

dune vegetation was destroyed by tides and drivers trying to avoid the sea. **Tropical disturbance** #8 on October 2 had a much greater effect on the beach: **9/30/94** - *"The tide has been up to dunes in places. Remnants of tropical disturbance #8; rain getting heavier; a ridge & runnel formation."* **10/2/94** - *"Tides have been up beyond the due to tropical disturbance #8. The dunes have been eroded all along. Strong surge today. Erosion of dune vegetation* [Photo]. *Truck inundated by wave."* This storm did erode the toe of the main dunes by a meter or so. **10/15/94** - *"High tide and rough seas due to low pressure from **Hurricane Rosa** (a west coast storm crossing over from Mexico). There has been heavy rain while I was away."* On **10/5/94** high tides prior to a norther *"swept the beach clean to the dune line."*

**4.17 1995**

No surveys were made prior to January 7 and between January 22-March 8. On January 22, Nueces County delivered a truck load of Christmas trees to the dunes. A wide beach on February 1 exposed the old metal posts at the shoreline, including the post at Mile 4, seen sporadically since Hurricane Allen. High tides on March 15 cut many channels through the berm. A big March storm on the 29th: *"Very windy and wet weather for two days. High tides. Considerable beach erosion due to high tides. Berm like a cliff now. A huge wave advances to the dunes and I have no where to drive the truck to escape. Did not get washed out to sea, however, the berm is far less eroded here* [at Gulf Shores] *meaning perhaps that the cleaning effort has reduced the amount of sand on the beach itself. The dunes are steeper and higher here perhaps due to artificial dune building from dumping weed & sand from the cleaning. The City of Port Aransas Parking Fee sign is down and floating in the sea. The 'Leaving Nueces County Maintenance Area' sign down and washed to here. The tide has come up beyond the dunes. Nueces County then scarfed the edge of the dunes, presumably to make way for traffic with the high tides."* The sea came up to the dunes several times in April too, and the beach in places was as narrow as it has been since starting BEACHobs. During May, heavy equipment was used extensively to remove weed and debris from the beach and pile it in sometimes mountainous heaps in the dunes, prompting me to express my concern about this practice in writing to the authorities. A Kemp's Ridley turtle was observed nesting between Markers 48 and 49 on May 17. As the nest could not be located, I asked the City to refrain from putting weed piles in the dunes at this location. They complied and we kept watch over the site for the next 60 days. No emerging hatchlings were ever seen. In response to my letters, the Corpus Christi Parks Commissioner stopped all heavy equipment use except near the condominiums.

**Hurricane Allison** made landfall near Apalachicola, Florida on June 5, but had no effect on Mustang Island beach. In June the owners of the Private Houses (Mile 6) requested that the County not clean in front of their property. On July 31, **Tropical Storm Dean** went ashore near Galveston, raising sea level here. Seas were calm but there was a strong southerly longshore current. Tides came up to the dunes and a ridge/runnel beach was formed. On August 7 **Hurricane Erin** went across Florida and became a tropical storm in the Gulf. No effect here. On August 10: *"**Tropical storm Gabriella** is going ashore to our south some time today. Big showers around. A huge rain squall moving inland to the south. Brief heavy rain. Now the sun shines and it is beautiful! Tides up to the dunes. Dune erosion due to tides but also cars having driven there to avoid the water. Very difficult to drive with sea coming in to the dunes. Had to*

*go to 4WD and got temporarily stuck (only one wheel in lock!). Today was a rare 'car-less' day."* The pledge by the County not to use heavy equipment was broken on August 18, and eventually forgotten altogether. A record high (morning) sea temperature of 30.21C (86.4F) was recorded on August 20. On September 15 I found a dead Stejneger's Petrel, a Pacific Ocean pelagic bird. It was the first confirmed record for the Atlantic/Gulf region. **Hurricane Opal** in early October affected our beach as described in the notes: *"Hurricane Opal now heading north. Will probably go ashore east of the Mississippi. Very high tides here. Essentially no beach. Sign floating in sea, City Parking Fee sign (green metal). The truck is inundated by the sea here. Video. Dramatic video of hurricane Opal seas with pelicans and the truck getting inundated. The sea is coming up beyond Gulf Shores Condo walkway. Dune erosion here. Dune erosion all along. The goat's foot morning glory has been considerably damaged. City of Port Aransas Beach Parking Permit sign washed to here. Several other signs down. The garbage which was scooped up with the weed and dumped in the dunes earlier this year is now being eroded back to the beach! My left front tire getting flat. Better get off the beach quickly! Many milk jugs, perhaps emerging from the 'garbage dunes'? In 4WD all the way. There were some exceptionally difficult parts. I think where 'cleaned weed' had been dumped. The truck was awash several times but have probably had a couple of other obs as hazardous as this one."* Opal went ashore the next day in Pensacola, Florida as a Category 3 storm. Here it left the coppice dune vegetation covered in wet sand and it ultimately died. The beach was planed flat and main dunes eroded back about 3 m (11 ft). Dunes in front of the Private Houses were eroded even though no beach cleaning was done there, **Hurricane Roxanne** went ashore in Mexico on October 13, pushing tides to the dunes again here. Pieces of rock and shelly material were pushed up on the beach by these tides.

A red tide(?) fish kill occurred in the latter part of October. On October 31 a stalled cold front caused high tides and further dune erosion. *"Little beach left. High seas today. A record rainfall on Sunday, 9.71" in Port Aransas. Stalled front pushed tides into dunes. Occasional waves coming up to the dunes. Driving in the sea. Erosion of dunes and damage to Gulf Shores walkway. There has been some dune erosion as well around Port Royal Condo walkway. Erosion of dunes and exposure of morning glory roots extensive. Considerable dune erosion at Private Houses. Photos. Well, I got all the way to here (mile 6.6) without encountering another person! Now a car with two surfers. Bah! 'Nueces County Sticker Required' sign down and destroyed here. Much more garbage on the beach, especially up in the dunes. Some is eroding from the dunes, some may have come from overturned trash barrels. There are especially many milk jugs. Most signs are down. Broken posts in surf zone. This event is as big as Hurricane Opal's tides."* The county used prisoners to hand-pick trash often this fall.

### 4.18 1996

No surveys were made between January 7-February 19, May 16-June 3, and after December 14. On January 7 the temperature was below freezing for the first time in five years. Wide beach following cold front. On February 28 I noted that the wind (22 kts) was winnowing sand from the beach except where the weed was still in place. In March several periods of strong winds (42 kts on March 19) stripped the backbeach of sand down to the hard-packed substrate. The Spring beach went through bi-weekly tidal cycles of alternating wide and narrow widths. By

March 23 a big effort to remove the weed resulted in a soft, rutted surface and "*very few cars*" negotiating the beach. So much material had been put into the dunes that on March 25, I had to "*back up because I didn't recognize Mile 4.*" In early April the Buffalo Barge oil spill coated Mustang Island Gulf beach with fresh tar and numerous sea birds were oiled. The response team undertook a massive cleanup effort and closed the beach off to the public on April 4. Much of the tar was swept from the beach by a late cold front on April 6. The tar and oiled birds came back on April 12 and crews continued to remove tar from the beach. A number of trucks and other gear was employed in the tar (and sand) removal on April 16 and, by the 18th crews were "*picking up microscopic pieces of tar.*" Beach raking continued, even when there was nothing to rake. On May 4, I noted, *"A large dune has built up in front of Private Houses walkway. Also it is obvious how the beach-cleaning has affected the beach either side of the PH's who asked the cleaning people not to clean here."*

The summer was mild and the beach remained stable with the exception of the "*huge mountains*" of weed and sand piled into the dunes from the raking and scraping operations. I remarked that it would be "*tough luck*" for any sea turtle that might nest in the dunes to have tons of sand and debris piled on the nest. On July 3, a "*Man running big front-end loader apologizes to me for what he is doing. 'I just have to do what I'm told,' he says. He tries to put the sand in 'the hollows' and he reduces height of piles to help the (nesting) turtles. The bulldozer has been working along with me, so to speak, all the way to the Port A. line here. It zooms along S/L. scooping up a pitiful amount of weed (there is almost none ashore), a lot of sand, and piling it in dunes, sometimes going far into the dunes to do so."* On August 24 **Hurricane Dolly** raised tides beyond the dunes but there was little dune erosion. On September 13 an outbreak of red tide (*Gymnodinium breve*) killed thousands of fish on Mustang Island and elsewhere. Of particular note were dozens of huge adult red drum (we counted 11,000 on San Jose Island). A very uncomfortable BEACHobs was made on September 15 with much coughing and eye and nose irritation. The red tide lasted until September 25. On October 5 I had to abandon the BEACHobs because the "*swells were threatening to float the truck out to sea.*" This was **Tropical Depression #10**. Two days later #10 turned into **Hurricane Josephine**, but most of the effect on our beach occurred when it was still a number. This was at Mile 2: "*An immense wave clobbered the truck and started it floating. I was outside but soaked to the waist up against the dunes. Good job I had closed the truck door. Considerable erosion of La Mirage walkway. Photos. Erosion of La Mirage walkway. This is the most erosion since Gilbert in 1988. Piles of debris & erosion by Mustang Towers. Photos. This is getting to be an adventure. Hope I get out of here! Picked a comparatively safe place to stop & take measurements and make notes. Photos of erosion at Port Royal Condo & my Mile 4 marker. Nueces Co mile 12 sign still standing but dunes gone shoreward of it. An ancient post here. Has part of the Private Houses walkway walked away? The only mile* [Mile 7] *where the datum is still shoreward of the dunes. Left my measuring wheel at Mile 6! Had to go back to get it in this dangerous sea/beach. An extra anxious 2 miles. The beach is littered with Christmas trees from dune-stabilization efforts. Much other driftwood, especially large pilings and stumps. That was probably the most adventurous BEACHobs of all time. Phew! I did not pay too much attention to counting trash. I needed to get off beach as soon as I could. A failing of my method was to get good mile-marker pictures before they were unutterably altered by the storm. Still, normally one has warning of an*

*erosion-producing storm. Remind me in a few years time to take pictures of the built-up dunes."* Josephine eroded the mid-beach to reveal the tips of the Civil War Wreck, not seen since September 1991. The dunes were eroded back about 10 m (33 ft) or more. The red tide and dead fish came back on October 13. After Josephine an effort was made to rebuild the dunes by pushing weed, sand, debris (including much plastic litter), and dead fish up to the dunes. Josephine also exposed the two high pressure gas lines between Miles 6 and 7. Vehicles began driving over the warped pipelines!

Tides continued to come up to the dunes for much of the rest of the year. By October 23 the pipelines had been buried by the company with warning signs planted. I had to abandon BEACHobs on November 18 because the sea was threatening to float a borrowed car (Toyota getting new timing chain) out to sea. On November 20 I experimented doing BEACHobs using a John Deere Gator vehicle. It is impracticable because it cannot be driven on the highway. The storms of late November were major beach erosional events (but not of the dunes). The gas pipelines were re-exposed and warning signs washed away. The company finally buried them properly on December 10. A major beaching of Portuguese Man of War (*Physalia physalia*) occurred in late November. These, too, were pushed into the dunes by beach crews.

**4.19 1997**

No surveys were done between January 9-February 19, May 19-25, July 12-August 3, October 7-12, December 9-21, and after December 25. A high tides in March was followed by a series of high spring tides in mid-April that reduced the beach to a few meters wide and penetrated to the dune line. On April 7 the second Toyota truck was used for the last time with 90,431 miles and six years of beach surveys under the hood. A new Dodge RAM 4WD pickup was given a trial run on April 11 under conditions of extreme high tide. I wrote that I was "*in a new $27,000 truck on a beach that doesn't exist with waves lapping the tires.*" The beach was very narrow throughout the spring, forcing many campers off the beach. The practice of grading a driving lane adjacent to the dunes became more common and had the effect of leaving a sand ridge at the toe of the dunes. This became a new dune line in many cases as sand collected between natural dunes and the ridge. In early May a second beach rake worked in tandem with the Barbour rake.

The tropical season was uneventful in 1997, with no mention of named storms in the notes. Some high tides in August broke over the berm and filled the runnel which, due to beach grading, is at a lower elevation than the swash zone. Towards the end of September high tides forced vehicles to drive near the dunes, destroying newly-formed coppice dunes. A minor outbreak of red tide in October resulted in a fish kill. 1997 was a generally uneventful year.

**4.20 1998**

No surveys were done between before February 5, between June 11-29, October 17-25, and December 2-12. The wide beach of early February was eroded by a big storm on February 15 that forced me to drive almost in the dunes and at one time decide to abandon the survey (but I could not turn the truck around). All advancing vegetation and coppice dunes destroyed. The spring of 1998 was characterized by a remarkable series of alternating, but diminishing, wide and

narrow beaches, that were tidally controlled. My Mile 4 post, the longest lasting of all the datums, ultimately succumbed in 1998. I was able to use it to gage vertical dune growth until it was destroyed November 16th. On March 15, I wrote: *"The Mayan Princess walkway ends short of the toe of the dunes. People going from condo to beach have eroded the dunes. What to do about this?"* This is a problem faced by all the condominiums with the advancing dunes. Ultimately they must extend their walkways. On April 6 I saw One-footed Ring-billed Gull for the last time. This bird had been wintering at the same place on the beach every year since 1979. A typical beach management event was noted on April 18: *"Front-end loader scarfing the dune edge and piling huge heaps of sand on dunes. There is no beach either! Sea coming up to my truck."* By the end of April, the Private House walkway I use as a datum had again "*become incorporated into the dunes*." Gulf Shores extended their walkway again by adding a ramp to the seaward end.on April 28. On May 5, *"Rival weed removal vehicles approaching each other: Nueces Co's Barbour Rake from the south and City of Port Aransas' front-end loader from the north. The birds scatter and their food supply goes into the dunes in ugly heaps."* On May 22 the Mile 4 marker was vandalized, reducing its height by 65 cm. The months of July and most of August were tranquil and the beach became stable during this period. **Tropical Storm Charley** came ashore on the night of August 22. It eroded much of the mid-beach vegetation and sand, and the main dunes were eroded slightly in places. I had another tense beach survey due to the sea coming to the dunes while I was driving. When the storm tide eventually went down, the beach had been planed flat. **Hurricane Earl** on September 3 (went ashore on the Florida Gulf Coast) also swept the beach clean. **Tropical Storm Frances** went ashore near Port O'Connor on September 11. Frances did considerable damage to Mustang Island dunes. On that day I managed to get 1.68 miles south of Access Road #1, but decided not to go farther ("*it would be foolish to try*"). Here are edited notes from September 11: *"Considerable encroachment here at Gulf Shores, about the same as with TS Josephine. The end of the walkway washed away. I measured to the end of the old walkway which is 44 paces to the condo itself* [during much of 1998 I reverted to pacing as I had bad luck with faulty surveyor's wheels]. *Most of the dunes have been diminished here. Debris washed over the dunes. Owner of Gulf Shores asks me best way to build up dunes. I think snow fence is the best but told him that this will happen every few years.* [At Mile 4] *Post is now 172 cm from sand!* [see Fig. 66] *I suspect that my ancient post will be removed by authorities now that it is several meters from the dunes (in the middle of the beach). We have lost 100 cm of dune (vertically) at my post location.* [At Mile 5] *My datum post has gone but I think I found the stump. I measured to this and will need to adjust my Mile 5 to the new walkway end for now. Wish I could find new datum. Video of destroyed walkway at Lost Colony.* [At Mile 6] *I think my datum (the end of the first walkway) is still intact. A front end loader has pushed all the big logs up to the dunes.* [At Mile 7] *The dunes have been eroded up to my datum post (15 mph sign) all the way to the post. This might be more than Josephine. Video of the now cleaned-up Access Rd #2 entrance* [ it was impassable yesterday]. *My initial summary of TS Frances - a little more than TS Josephine."* About 10 m (33 ft) of dune was eroded by Frances. **Tropical Storm #8**, later **Tropical Storm Hermine**, went ashore near New Orleans on September 21, giving rise to high tides on Mustang Island, but no dune erosion. **Hurricane Georges** hit the Mobile, Alabama area on September 28. Tides rose rapidly on September 27 here due to George, and the truck was frequently awash doing the survey. Cars had to drive landward of the mileage posts on September 29. Various condominium walkways

were repaired into October, but high tides persisted. A "shield" of sand built up in front of the dunes eroded by Frances and I measured to the base of this shield. It was particularly difficult to measure the Mile 1 datum as this was the only post left landward of the dunes and I had to climb a 6-ft vertical wall to get to the post (trying not to disturb the dunes). On October 17 the County sprayed the dunes (and me) for mosquito control. In late October the beach was reduced to nearly nothing with a **tropical disturbance** in Campeche. By mid-November, the Mile 4 post was vandalized again and I reluctantly shifted my datum point to the walkway at Mustang Island Beach Club. A front-end loader was employed at Gulf Shores to make dunes in front of their property. As the year ended, the beach recovered from the erosion events of fall and widened.

**4.21 1999**

No surveys were done between January 5-3, January 31-March 4, and March 24-April 11. On January 17, "*A big bulldozing job done here at Gulf Shores. Sand has been dozed up from about 13 m of the backbeach to build dunes in front of the condo. I've got to find out if they can legally do this* [never did]." Christmas trees were placed in front of the dunes at various locations, many still bearing tinsel and some never sold. The HP 75 failed and I obtained two of these obsolete computers via collectors on the Internet. Had to do some surveys the old fashioned way. Wide beaches formed at the end of February, but not as wide as "beaches of old". 1999 was a big weed year and it came in earlier than usual (in March compared to May). In front of the condominiums graders and front-end loaders started scraping the entire beach rather than just the swash zone. Front-end loaders and trucks are moving tons of weed and sand laterally from where they scraped to form artificially steep "dune walls". In early May, high tides forced vehicles to drive between the mile posts and the dunes in the City of Port Aransas limits, destroying new growth. Where *Sargassum* is left intact on the beach, it has acted to stem the rising tides of May from reaching the dunes as it has elsewhere. By late May the beach rapidly built up and widened, remaining wide for the summer. The surveyor's wheel also failed and two replacement units also failed (manufacturing fault) so I reverted to pacing for a month, trying several different wheel before settling on one model in early June. In late June I tried a survey-grade differential GPS system to see if I could do profiles with the "sub-centimeter" GPS systems. The test was not particularly successful, due to frequent loss of signal from the master station (also, I looked like a Martian with gear strapped to my back and an antenna above my head). A **tropical depression** that went ashore in the Gulf of Campeche, Mexico, pushed tides to the dune line disrupting July 4 beach-going. On August 11 I remarked that at Mile 1 "*The dunes are now beautiful here. A smooth shield slopes up to the main dunes and tendrils of morning glory are creeping seaward to enhance the dunes.*" Yet at Mile 7, "*The dune line formed by blown sand is very variable, changing from day to day so my measurements will show this variability.*" On August 21 I noted that the **tropical disturbance** in the Gulf of Campeche was having no effect here "*other than some clouds*". The storm rapidly developed into **Hurricane Brett** and made landfall in Kenedy County to the south. We evacuated Mustang Island but got back on August 23. The next day's survey: "*The storm did very little damage to the dunes. Here the highest HT/L is at the dune line (39.6). There has been erosion of sand on the beach. A huge quantity of garbage has been exposed at the shoreline especially pieces of plastic and plastic bags. The ridge of sand that had formed at the toe of the dunes has been eroded away here but tendrils of morning glory seem to have been unaffected.*" 14" of rain (a

record) fell on Mustang Island on August 23. Following Brett, the County removed tons of garbage left by the storm and put it, along with the weed, into the dunes. This has become a trend recently; to abjure hand-cleaning of marine debris for piling it in the dunes. I remarked, "*They have stored for a future event*". A **tropical depression** to the south raised tides halfway to the dunes on September 6. By the end of September, a huge effort by the County to clean the beach of all debris had left it "*looking like a sterile sandlot.*" The highest tide of the year on October 5 did not erode the main dunes but destroyed most of the incipient dunes building on the backbeach. A frequent operation at both access roads is to use a front end loader to push sand from the apron ways into the sea. The access roads are often the place where beach-going vehicles get immediately stuck. Wide beaches at the end of November gave way to strong southeasterly winds with tides to the dunes in early December. A brush fire on the dunes in December damaged the Private Houses walkway I use as a datum. A new walkway was built and I made the appropriate adjustments to the measurements. Tumbleweed was the main debris on the beach for several days. No surveys were done from December 20 to the end of the year.

### 4.22 2000

The series ends on June 30. There were no surveys made before January 12, between February 15-22, March 26-5 April, and May 26-June 12. This was a year of massive *Sargassum* weed beaching, the most since 1989. Weed started coming ashore in January and continued throughout the first half of the year. There was much public comment about the weed and a continuous effort was mounted to remove it using heavy grading equipment and front-end loaders. Different techniques were employed by the City of Port Aransas and Nueces County involving trenching the weed, and creating artificial berms to facilitate beach driving. The use of the less-destructive beach rakes has essentially been discontinued. One consequence of the various techniques has been to pile massive heaps of weed and sand on either side of the condominium beach fronts causing normal tides to penetrate farther in front of the condos. On February 3 high tides pushed weed up to the dunes. The 3000$^{th}$ BEACHobs survey took place on February 6. On February 25 the nose-cone from the French rocket Ariane V washed ashore (it was later taken by local residents to use as a hot tub, buried in their backyard). It had floated from French Guiana, 3,500 miles from Mustang Island, and taken 500 days to get here. By May 5 so much material had been put in the dunes by Mile 2 that it was almost impossible to reach the datum post. The spring was characterized by strong southeasterly winds and in early May, tides were up to the dunes. The City of Corpus Christi annexed part of the survey beach and put in city limit signs at mile 6.55. A walkway for the Religious Retreat was constructed at mile 5.4. The beach was very rough and dry as we went into a drought cycle and weed removal continued. It became more difficult to determine where the dune line was located at all measurement sites.

## 5. RESULTS OF GULF SHORES MEASUREMENTS

In the following section units of distance were measured in meters but are here also presented in feet to comply with most reports in the literature on beach erosion. Gulf Shores condominium was completed in 1978 and was one of two condominiums built at the same time (the other is Lost Colony). Both were built almost on the beach near the main dune line. No other structure has been built to date that is as close to the sea as these. The charted shoreline opposite Gulf

Shores is at 27°44.75'N, 097°07.17'W. To observe erosion/accretion of the shoreline, it was necessary to relate the measurements made at Gulf shores to a "benchmark" The benchmark used was the Gulf Shores wall facing the sea. Over 21 years numerous changes have occurred in the infrastructure of the Gulf Shores property facing the beach. It has been impractical to measure directly to the wall so various datum posts, fences, and walkway terminuses had to be used as one was altered or destroyed. Table 6 lists the various datums used and dates of their use. Figure 7 shows the relationship between measurements made at Gulf Shores and calculated locations of shorelines and dune lines.

### 5.1 The effect of tide, time, and beach profile

It must be noted that these data are dependent on the height of the Gulf tide at the time of measurement. The complex relationship between astronomical tide height and beach width is explored in a work in progress (Amos, in prep.). Here, a brief outline is presented. Tides at the Texas coast are tropical/equatorial in nature, giving rise to week-long periods of diurnal tides with a large range, followed by week-long periods of semi-diurnal tides with little range. Figure 8 shows the predicted tides for the month of May 2000 with lunar phases and times of sunrise and sunset for Port Aransas. Using actual tidal height measurements, the mean daily tidal range over a year is 0.356 m (1.16 ft), with a maximum daily range of 0.720 m (2.36 ft) and a minimum of 0.128 m (0.42 ft). Measurements are made at the UTMSI gage located at our Pier Laboratory on the South Jetty of the Aransas Pass. In addition to the daily tidal variability, there is an annual and semi-annual fluctuation in sea level upon which the daily tides are superimposed. Smith (1985) has discussed the local effects of these long-term tides on the local environment. Sea levels are lowest in winter, higher in spring, are low again in summer, and at their highest level in the fall. Meteorological effects, especially winds, are partly responsible for this variability (Davis and Fox, 1975).

The beach width is also dependent on the slope and morphology of the beach. Figure 9 is a typical profile made at Gulf Shores condominium on October 3, 1984 (John Snedden, personal communication, 1985). Note that the total elevation of the beach above Mean Low Water (MLW), the condition at the time the profile was made, was 300 cm (9.84 ft) and the distance to the shoreline from the condominium wall was 80 m (262 ft). The signs were pedestrian crossing signs, between which vehicles on the beach were supposes to drive (i.e., they mark the location of the driving lane).

As mentioned above, measurements are made near sunrise on each survey. How much does the tide typically vary throughout the year at the time measurements reported here were made? Figure 10a plots the daily tide height at the UTMSI gage at dawn (ignoring Daylight Saving Time) for the year 1998. At the latitude and longitude of Gulf Shores dawn varies from earliest (0532 Central Standard Time [CST] on June 10) to latest (0721 CST on January 11), a span of 1 hour 49 minutes. As a consequence of time of day and season that the measurements are done, both the fortnightly change from equatorial to tropical tides and the long-term seasonal rise and fall of sea level are encountered on the surveys. Low tides occur at sunrise in the first months of the year, high tides in April, May, and June, lower tides in July, and high tides in September and particularly October (Fig. 10a). These fall tides are often augmented by tropical storms as

Table 6. The various datums used at Gulf Shores in doing beach width measurements.

| DATE | OBS# | YRDY | DATUM USED | DATUM | BENCHMARK |
|---|---|---|---|---|---|
| 14 April 1978 | 1 | 104 | No measurements | -- | -- |
| 11 October 1979 | 76 | 284 | Dune line | 0.0 | 43.0 |
| 11 August 1980 | 189 | 954 | Gulf Shores Wall | -43.0 | 0.0 |
| 03 September 1980 | 199 | 977 | New Fence | 3.2 | 46.2 |
| 01 October 1980 | 212 | 1005 | 2nd Fence | -20.0 | 23.0 |
| 19 January 1983 | 509 | 1855 | 3rd Fence | -26.7 | 13.8 |
| 28 February 1986 | 1223 | 2981 | Gulf Shores Walkway | -15.6 | 27.4 |
| 13 February 1994 | 2200 | 5888 | Extended Walkway | 4.2 | 38.8 |
| 28 April 1998 | 2744 | 7423 | New Walkway Ramp | 2.9 | 40.1 |
| 12 September 1998 | 2802 | 7560 | Walkway after Frances | 7.9 | 35.1 |

**Key**: OBS#=BEACHobs survey number, YRDAY= number days elapsed since January 1, 1978, DATUM USED=description of datum to which measurements were made, DATUM= distance in meters of current datum to original datum (positive seaward, negative landward), BENCHMARK=distance from original datum to "benchmark" (Gulf Shores wall).

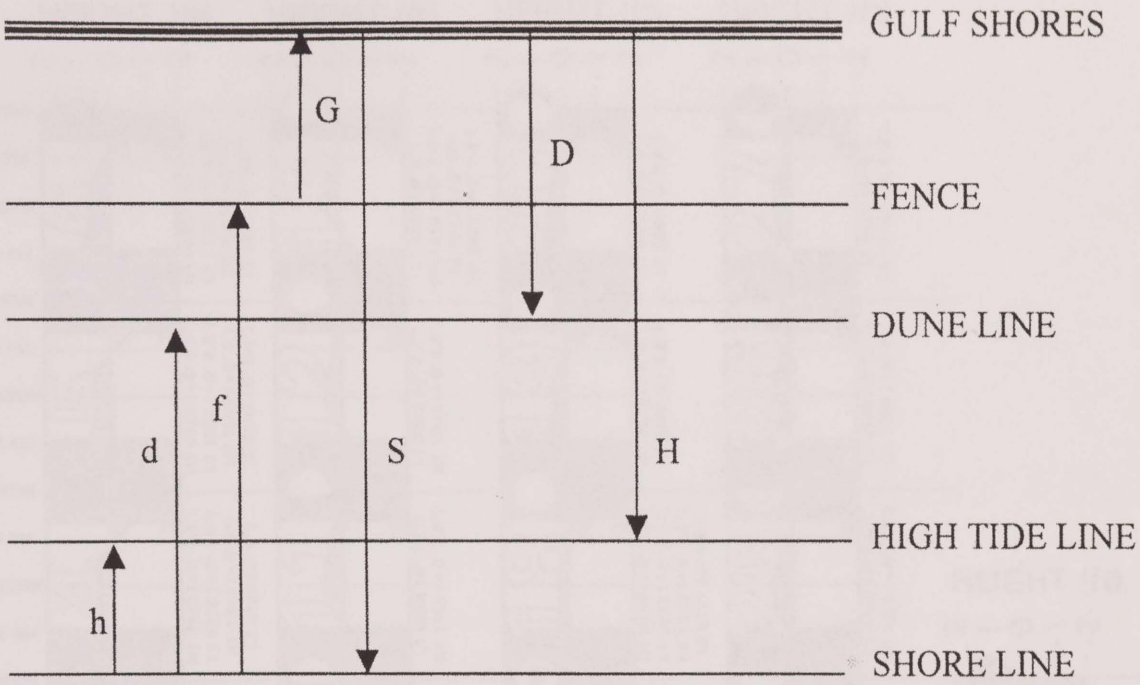



Figure 7. Schematic of measurements made at Gulf Shores condominium and calculation of distances used in monitoring erosion/accretion. Lower case--actual measurements made at each observation; Upper case--calculated distances. Key: h = shore line to high tide line; d = shore line to dune line; f = shore line to fence line; G = Gulf Shores wall to fence line; S = location of shore line (f+G); H = location of high tide line (f+G-h); D = location of dune line (f+G-d). The dune line (vegetation line) was used as the measuring datum prior to 1983. After Hurricane Allen, the dune line was contained by a number of fences used for dune restoration. All datums used were referenced to the condominium wall facing the sea.

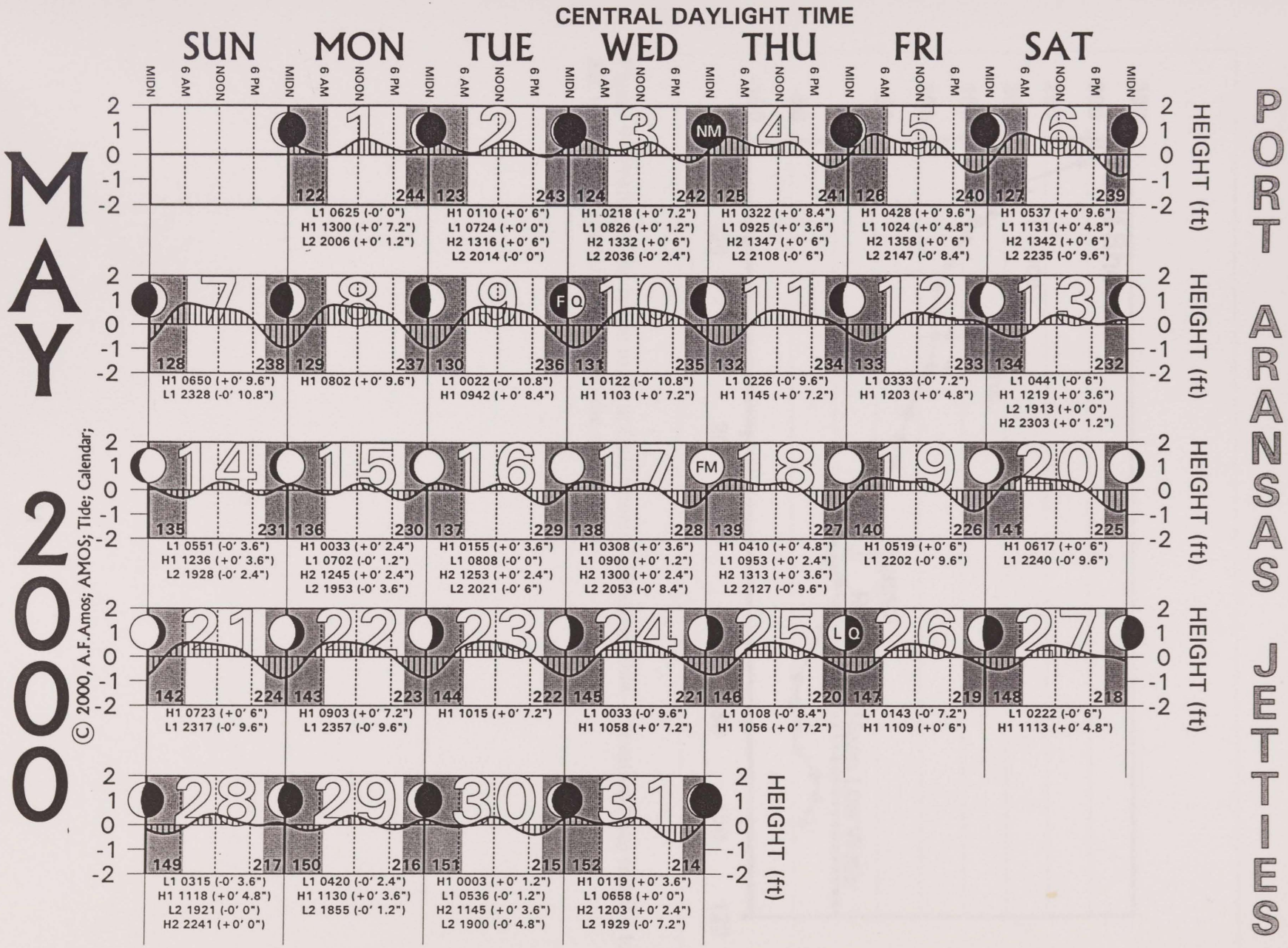



Figure 8. Calendar of predicted tides at Port Aransas, Texas, for May 2000.

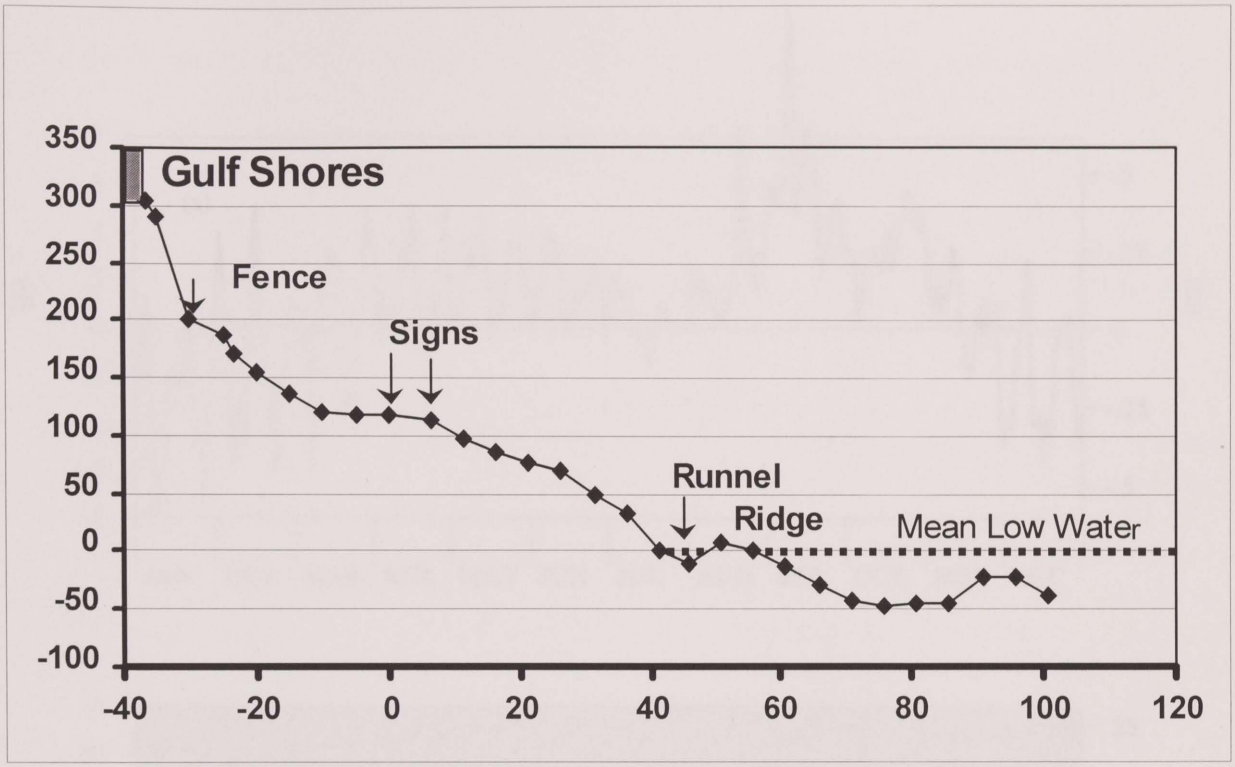



Figure 9. Profile of the beach made at Gulf Shores 3 October 1984. Elevation (cm) relative to MLW, distance (meters) relative to the second sign.

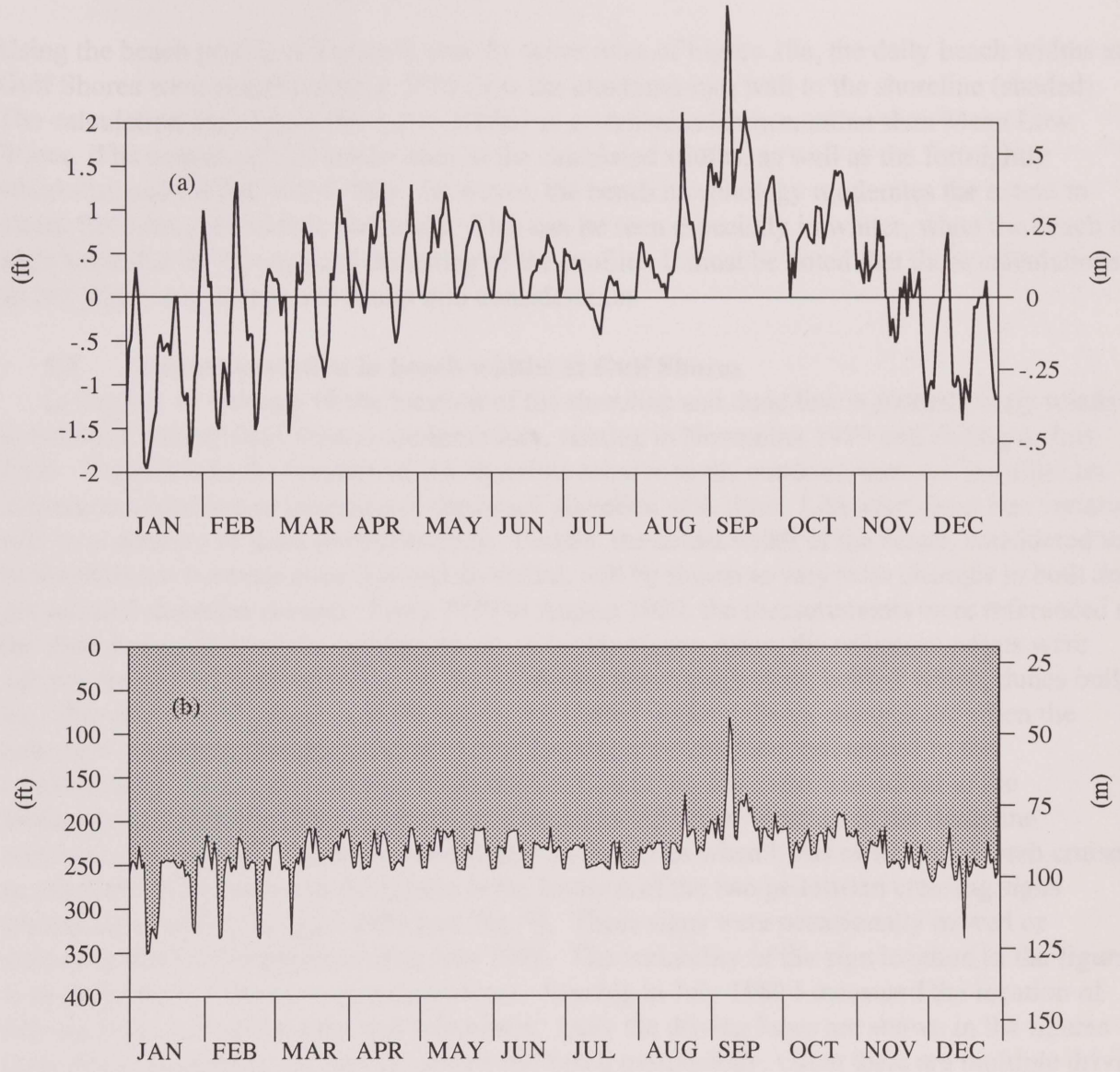



Figure 10. The relationship between tide height and beach width at the time BEACHobs measurements are made (near dawn on each survey). (a) The tidal record for 1998, measured at the tide gage on the UTNMSI Pier over the Aransas Pass Ship Channel. (b) Width of beach at dawn at Gulf Shores in 1998, calculated using a beach profile made on October 3, 1984 (see Figure 9). The beach width is relative to the Condominium wall that faces the sea (zero on scale).

occurred in 1998 with **Tropical Storm Frances**, while the low tides of winter are depressed when strong cold fronts sweep through the region.

Using the beach profile of Figure 9, and the dawn tides of Figure 10a, the daily beach widths at Gulf Shores were calculated (Fig. 10b) from the condominium wall to the shoreline (shaded). The calculation used Mean Sea Level (MSL) as a vertical reference, rather than Mean Low Water. The annual pattern can be seen in the calculated widths, as well as the fortnightly variability and the fall storm tides. However, the beach morphology moderates the extent to which the tides encroach on the beach. This can be seen especially in winter, when the beach is extra wide due to the seaward flattening of the profile. It must be noted that these calculations do not take wave energy and runup into consideration.

### 5.2 Annual variation in beach widths at Gulf Shores

In Figures 11 through 18 the location of the shoreline and dune line is plotted yearly relative to the front wall of Gulf Shores condominium, starting in November 1979 and ending in July 2000. Variations in the location of the shoreline relative to the condominium are therefore an indication of erosion or accretion of the beach shoreline with time. Likewise, dune line variation will be a measure of dune growth/erosion. Finally, the actual width of the beach, considered to be the distance between dune line and shoreline, will be shown to vary with changes in both dune growth and shoreline erosion. From 1979 to August 1980, the measurements were referenced to the dune line in front of the condominium. After Hurricane Allen, the reference points were various fences and barriers put up by the condominium management, behind which, dunes built up. This shows in the figures as the unvarying shaded region (abrupt changes are when the reference point was changed). All shoreline locations are absolute, referenced to the condominium wall. After October 1988 the location of the dune line was added to the measurements and from then on the shaded region is the actual location of the dune line referenced to the wall. There are several gaps in the series when I was away on research cruises or vacation. Also shown in the figures is the location of the two pedestrian crossing signs (diamonds), starting in April 1981 (see Fig. 9). These signs were occasionally moved or destroyed and finally removed after July 1988. The variability of the sign location in the figures is an indication of the error of measurement. Starting in July 1980 I measured the location of driving lanes, berms, runnels, and weed lines. Only the driving lanes are shown in the figures (gray lines) because beach driving affects the beach morphology. Often there are multiple driving lanes and the beach can be rutted with tire tracks from shoreline to dune line. Note that drivers seldom drove between the signs as required and, by August 1988, the last sign disappeared.

The first significant event was Hurricane Allen on August 9, 1980 (Fig. 11, middle panel). The effect of Allen at Gulf Shores is illustrated on the front cover. The dunes were not breached by Allen and sand eroded from them was deposited seaward, widening the beach considerably in the days after the storm's passage. Hurricane Gilbert on September 16, 1988, eroded the dunes, pushing the dune line back by an average of 17.5 m (57 ft). It was after Gilbert that I started monitoring the dune line at Gulf Shores (Fig. 14, top panel) and at the other mile intervals. Gilbert had a similar effect as Allen in creating a temporarily wider beach. Dune erosion also occurred with three tropical storms: Josephine on October 5, 1996 (Fig. 16 bottom panel),

Charley on August 22 1998 (Fig. 15, middle panel), and Frances on September 11, 1998 (Fig. 17, middle panel). Note the similarity between Figure 17, middle panel, and the "theoretical" beach width calculated for 1998 using an actual beach profile (Fig. 9).

### 5.3 The 21-year trend

The series of measurements made at Gulf Shores condominium is 21-years long, with nearly 3,000 surveys. The overall trend in shoreline location, beach width, and dune growth is clearly illustrated when the series at Gulf Shores is combined (Fig. 19). After October 1988, when dune location measurements started, the dune line (upper panel) progrades seaward indicating dune growth. This growth has been arrested by the tropical storms, but continues to grow following the storms. The location of the shoreline has regressed landward since Hurricane Allen (upper panel, Fig. 19) indicating an erosional trend. The result is a narrowing of the beach (middle panel). Dune growth is shown in the lower panel of Figure 19. An examination of Figure 19 shows that there is variability in these tendencies. For years at a time there seems to be little trend and in some years there are dramatic changes occurring over a month or two. These data include one-time storm events, and daily, fortnightly, semi-annual, and annual tidal effects, and the annual bi-modal nature of the overlying wind field (see section 7).

To examine the beach changes more closely, and to estimate the magnitude of these changes, the series at Gulf Shores was divided up into three epochs within the 20-year series. Epoch One occurred from 1979 to the fall of 1982. This includes Hurricane Allen in August 1980, which was arguably the biggest event of the entire series. This was a time of beach growth. In the fall of 1982 that growth appeared to diminish and the beach remained stable to partly erosional until Hurricane Gilbert in September 1988 (Epoch Two). Epoch Three lasts from Gilbert to the present time. This was a time of steady shoreline erosion, dune growth, and a narrowing of the beach. It is unfortunate that I only chose to examine dune erosion/accretion from Hurricane Gilbert to the present. At the start of this survey I was more concerned with the width of the beach and the swash zone as it effected bird foraging. Nonetheless, the shoreline changes are absolute from the beginning because these are referenced to the condominium wall. Also, the datum fences that were my sub-benchmarks did, in fact, bound the beach itself as dune growth did occur after Allen behind these barriers and ultimately overtaking them, when I switched to using the walkway. I decided to continue using this site as my main measuring location despite these artificial changes. It must be noted that the condominium is also a site of much human activity that has increased with time. This is another unfortunate aspect of performing multi-year surveys. However, I have made an attempt to document these activities, especially those involved with beach traffic, beach grading, and weed removal.

Figures 20 through 23 show shoreline, dune line, and beach width changes in the three epochs, and also over the entire 21-year period. All data in these figures have been smoothed using a ten-point running mean. Linear regression lines have been plotted, and the total change and change per year calculated from the regression. In Figure 20 the shoreline as measured at the time of observation is used. Notice that the $R^2$ values are very low in these regressions due to the large variance in the location of the shoreline at the time of measurement with tidal cycle as well as measurement uncertainties (see Section 2.8).

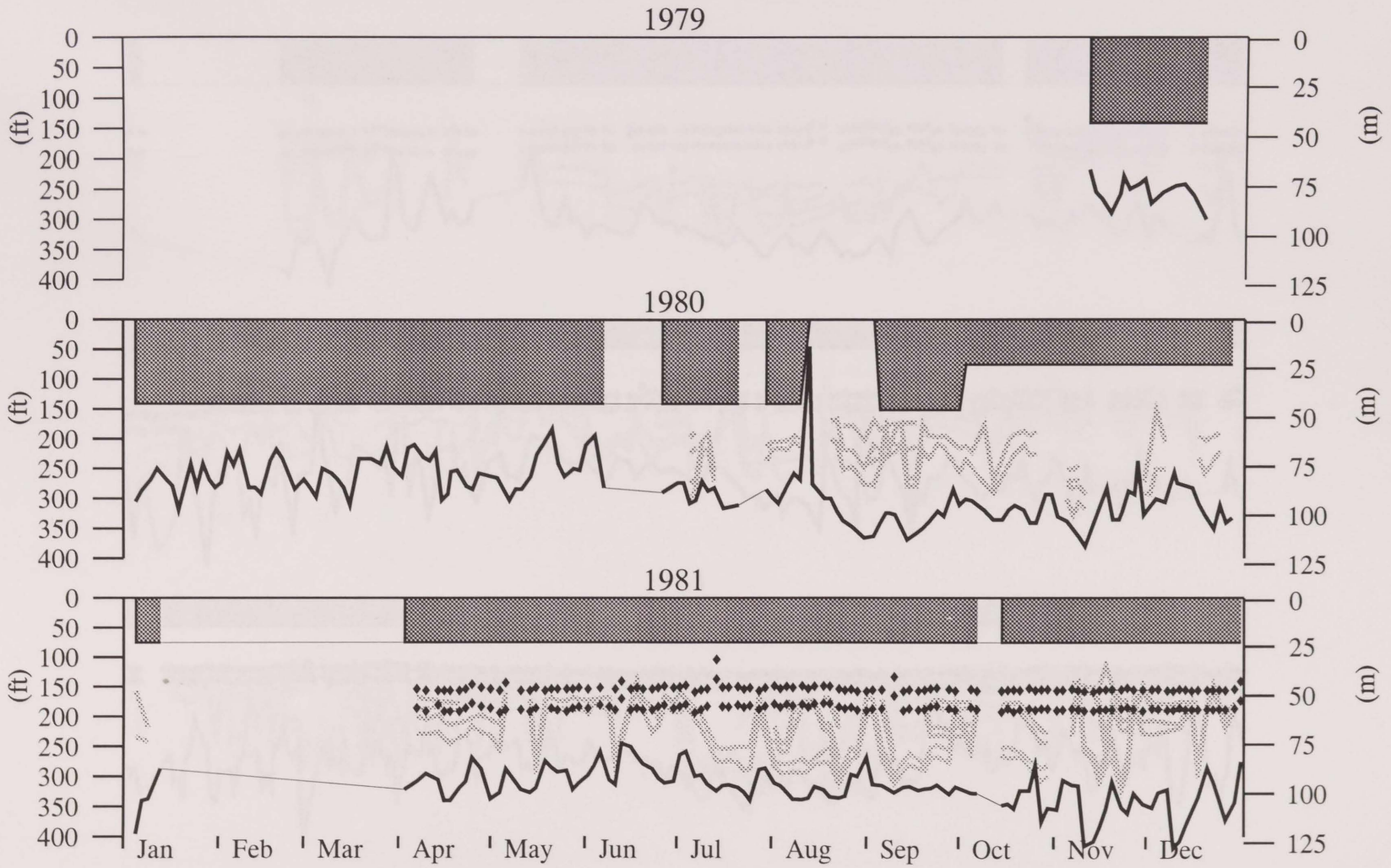



Figure 11. Location of shoreline, driving lanes and dune line at Gulf Shores: 1979-1981. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

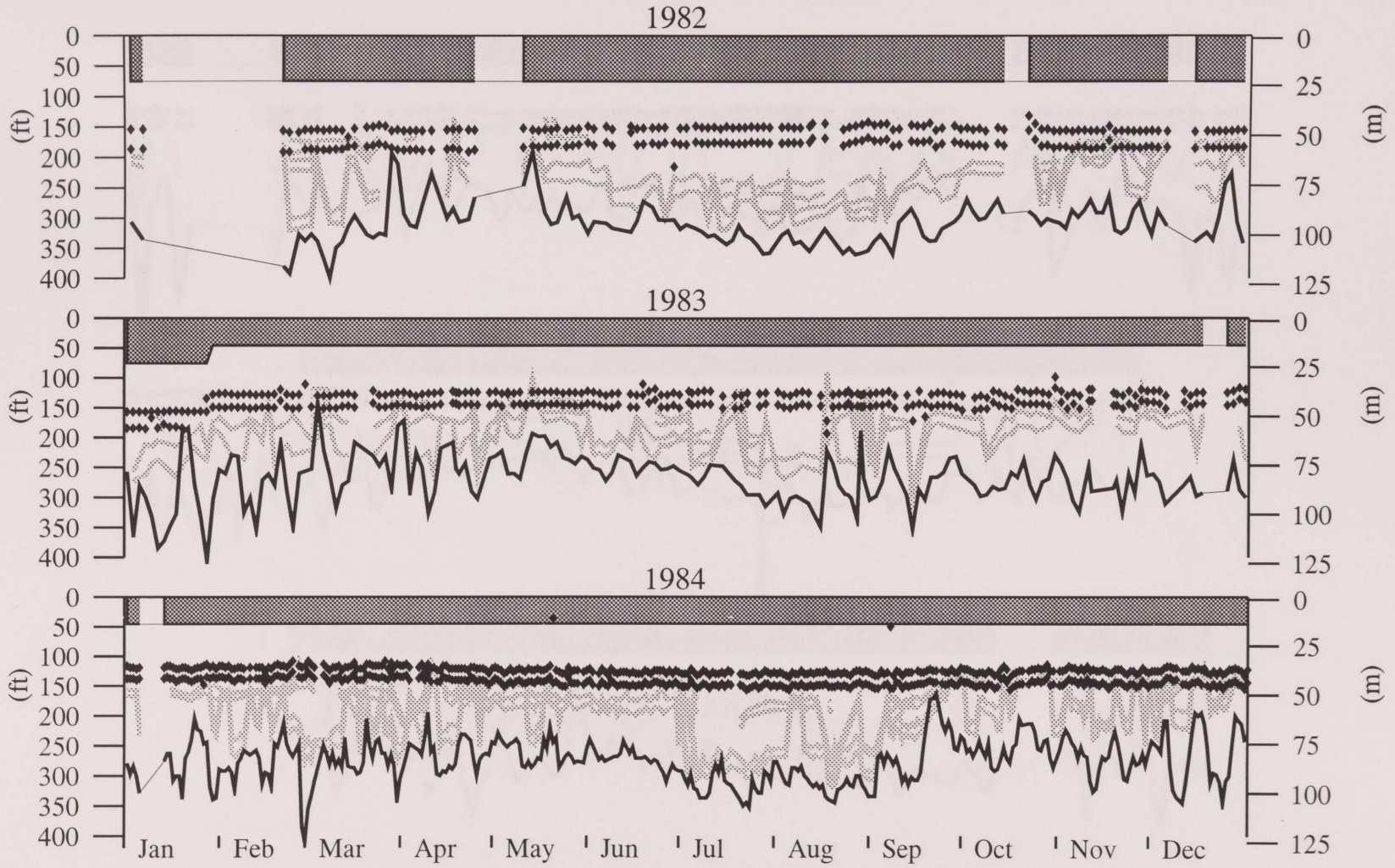



Figure 12. Location of shoreline, driving lanes and dune line at Gulf Shores: 1982-1984. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

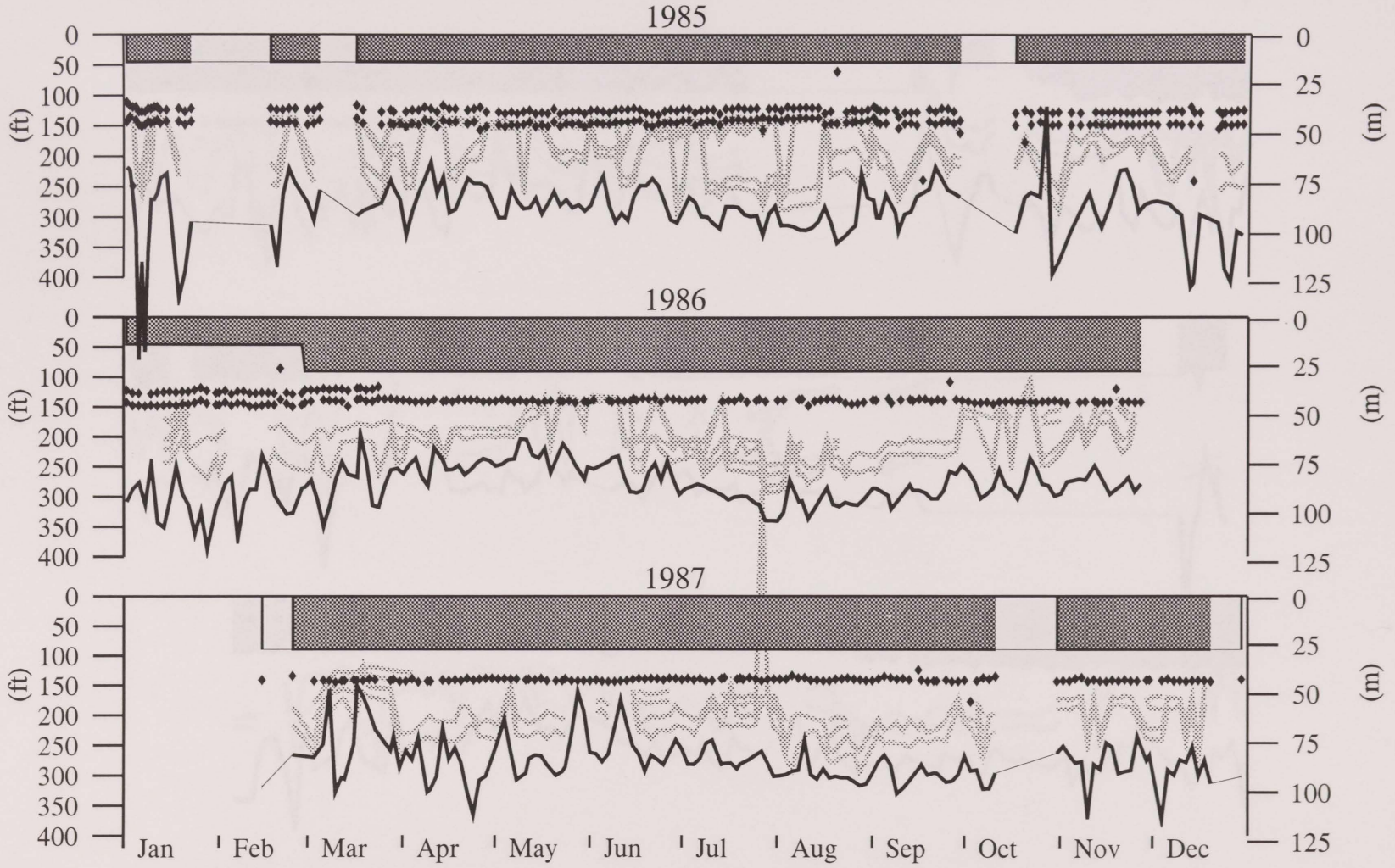



Figure 13. Location of shoreline, driving lanes and dune line at Gulf Shores: 1985-1987. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

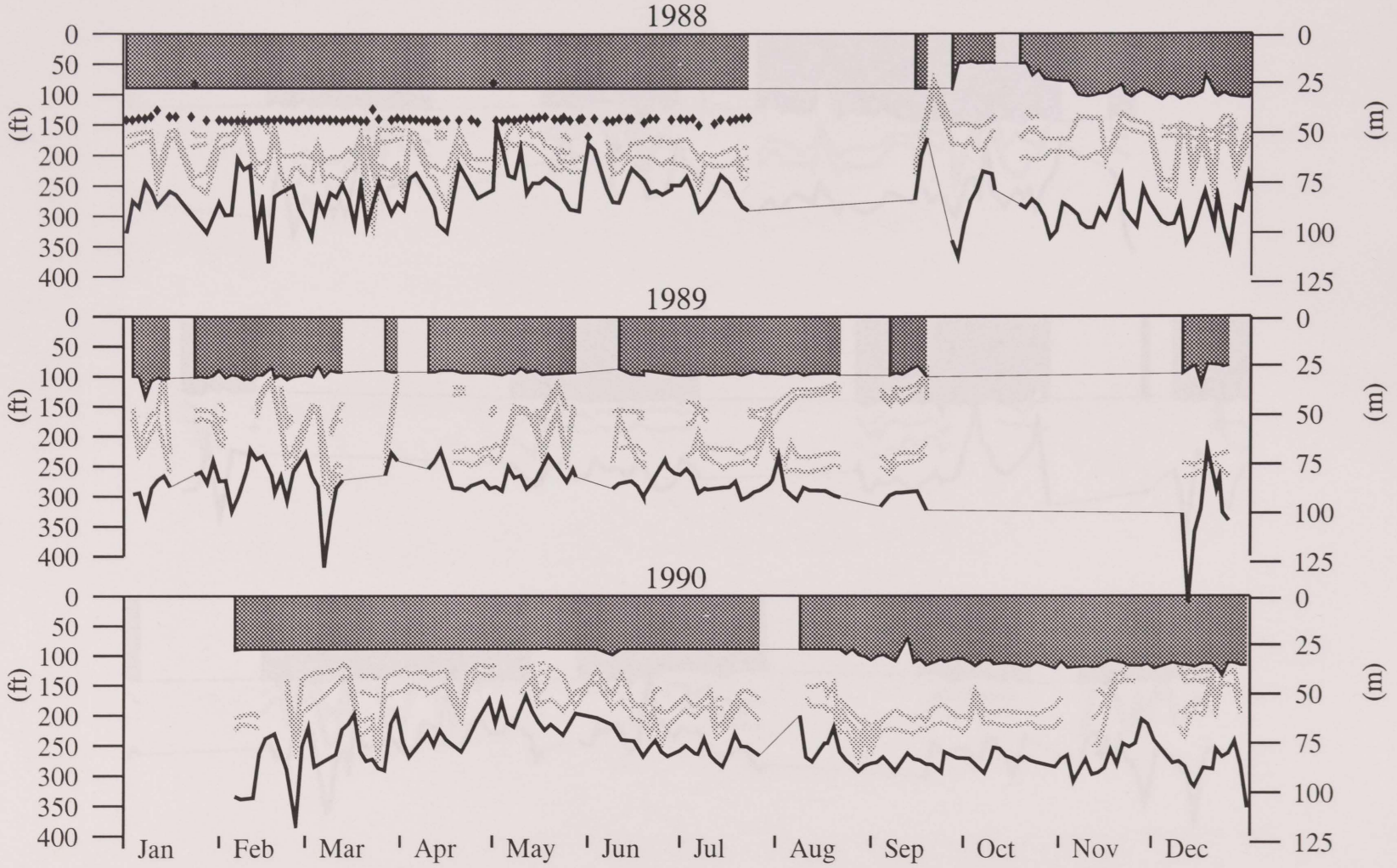



Figure 14. Location of shoreline, driving lanes and dune line at Gulf Shores: 1988-1990. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

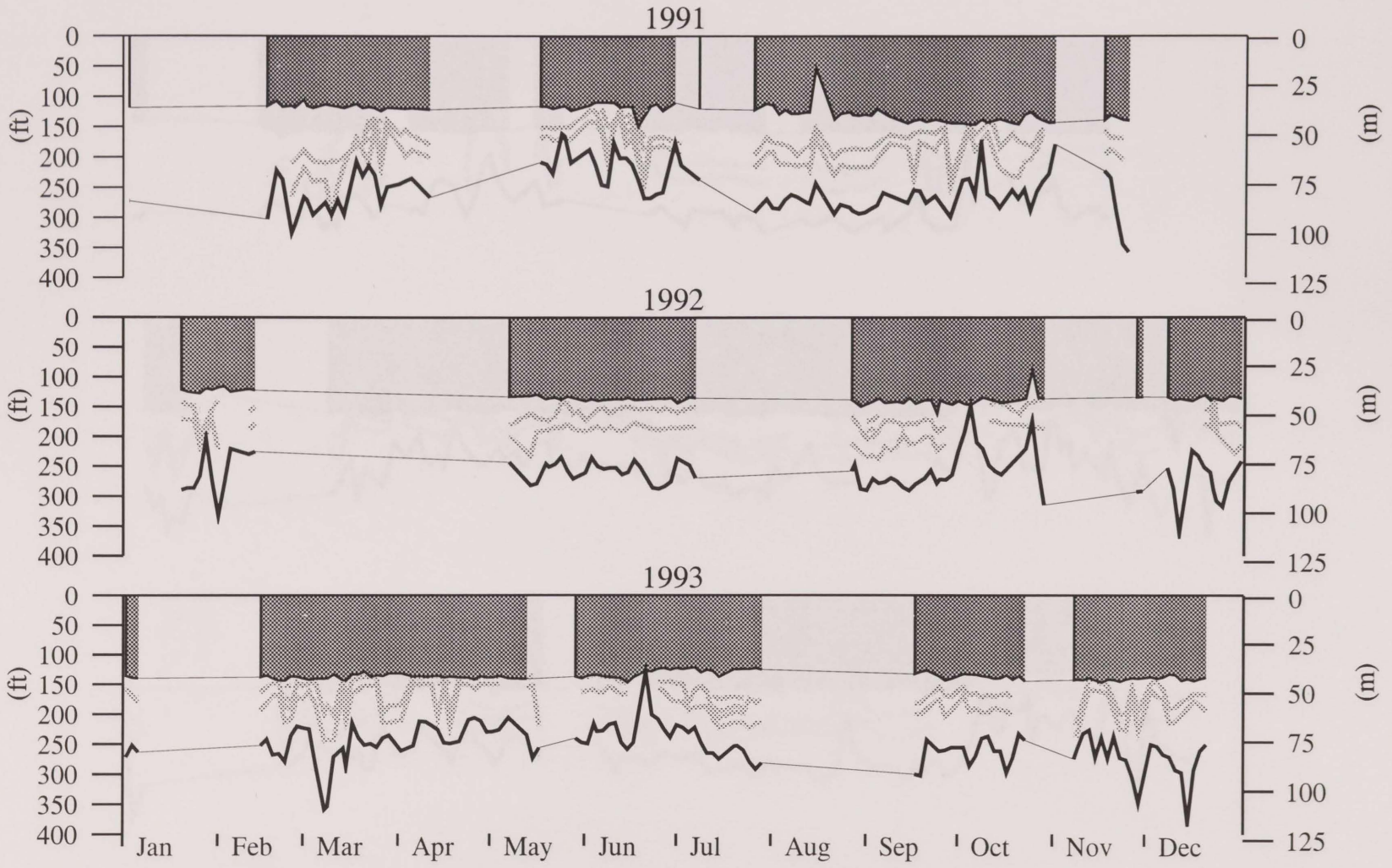



Figure 15. Location of shoreline, driving lanes and dune line at Gulf Shores: 1991-1993. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

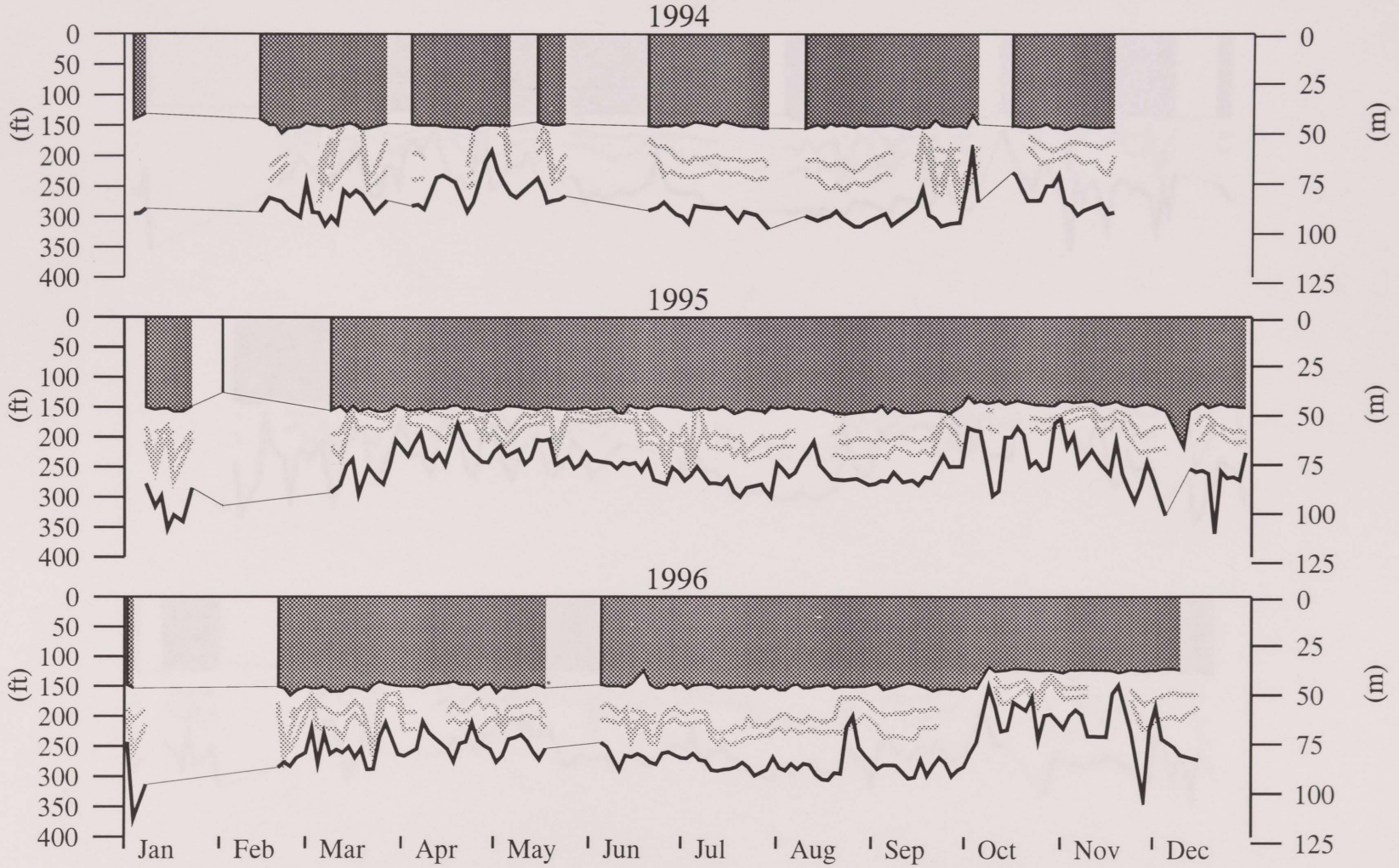



Figure 16. Location of shoreline, driving lanes and dune line at Gulf Shores: 1994-1996. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

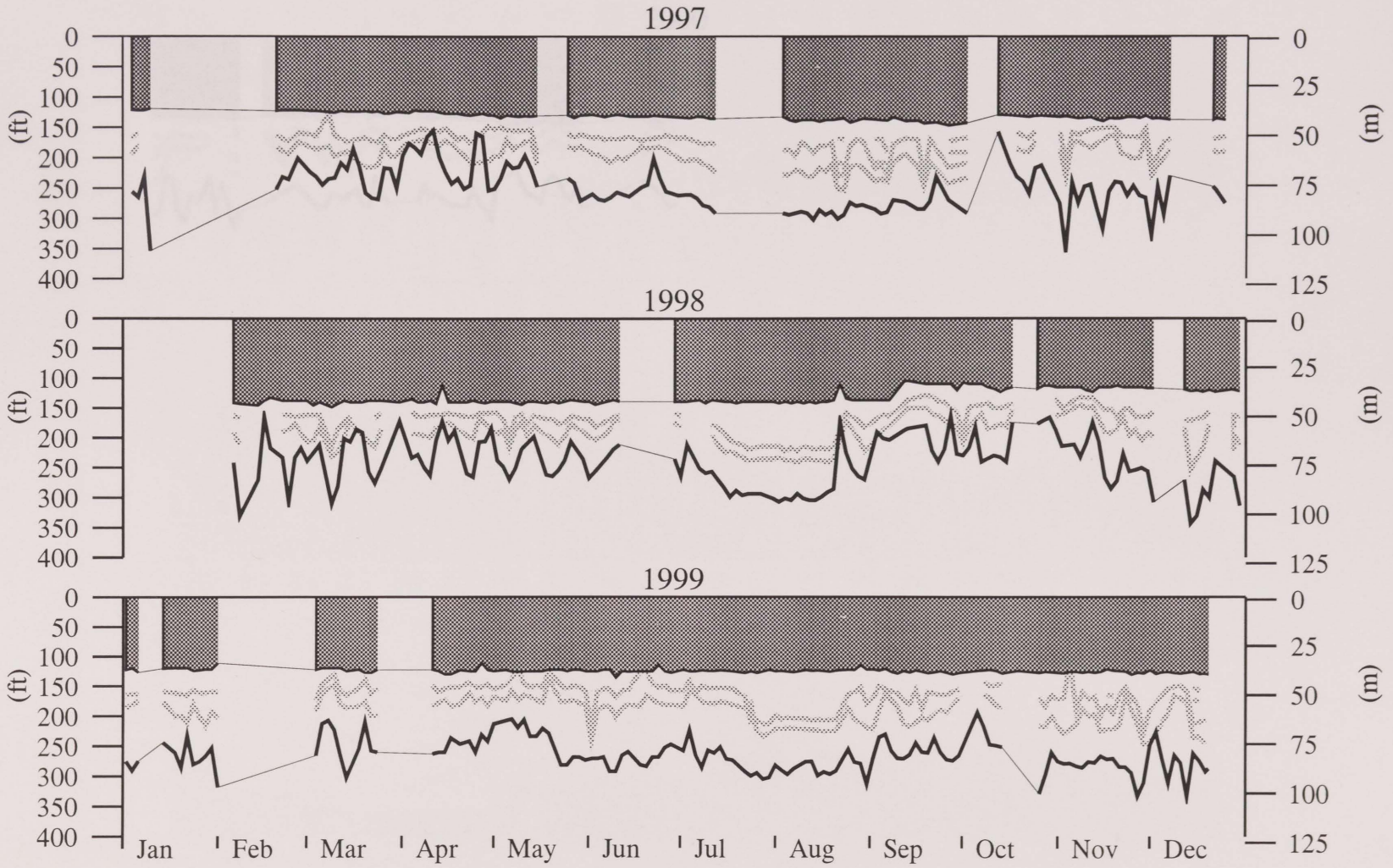



Figure 17. Location of shoreline, driving lanes and dune line at Gulf Shores: 1997-1999. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

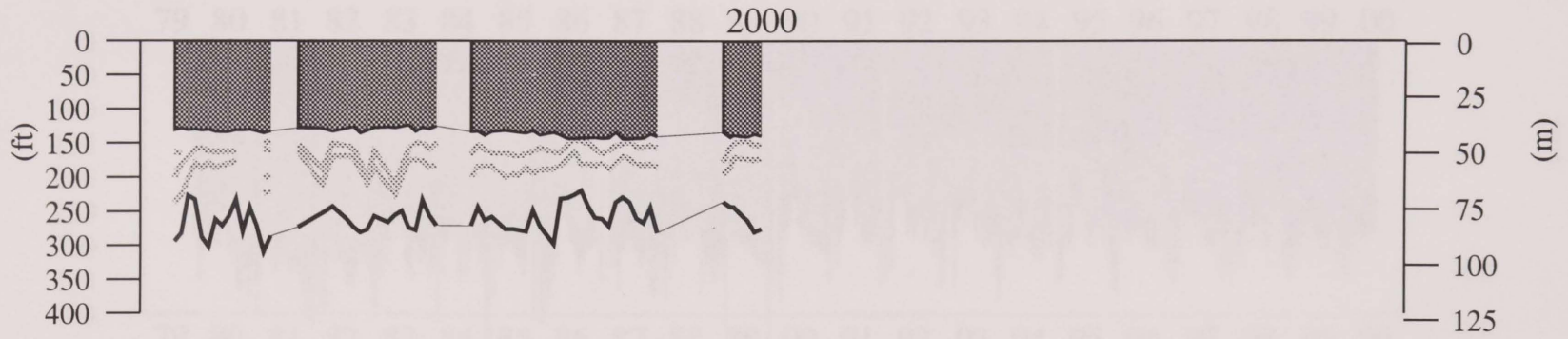



Figure 18. Location of shoreline, driving lanes and dune line at Gulf Shores: 2000. Shoreline is heavy black trace; driving lanes are between gray traces (occasionally there are multiple lanes); Shaded region depicts location of dune line relative to Gulf Shores Condominium wall facing the sea (zero on scale). The year is shown above each panel.

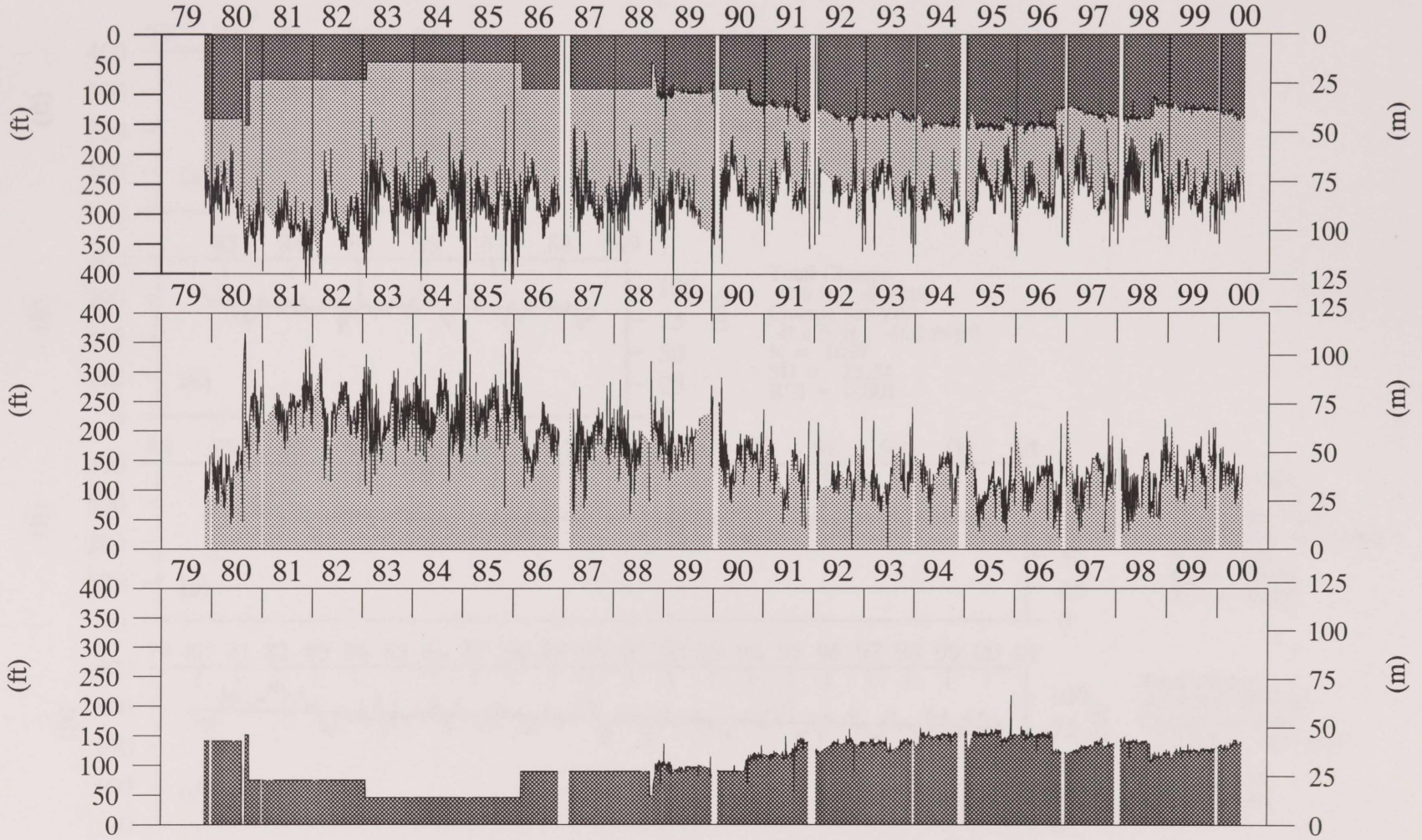



Figure 19. Twenty-one years of changes to the beach and dunes at Gulf Shores: 1979-2000. Top panel is a "plan view" with the condominium wall facing the sea at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the condominium wall. The years are shown at the top of each panel.

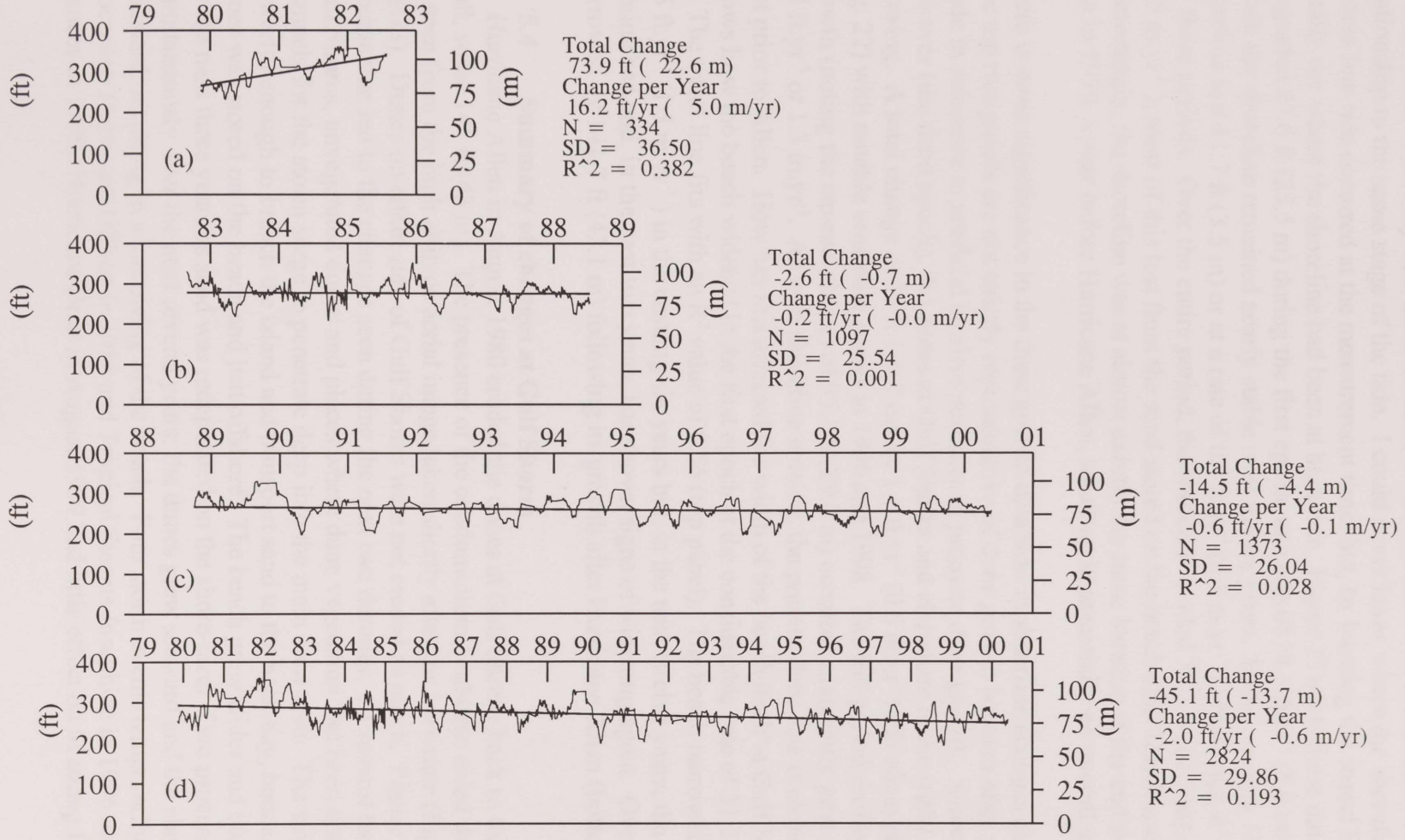



Figure 20. Erosion/accretion of shoreline (using location of shoreline at time of measurement) at Gulf Shores: 1979-2000. Each panel shows the location of shoreline relative to Gulf Shores Condominium wall facing the sea (zero on scale) for epochs of years with similar trends. The data has been smoothed with a 10-point running mean. The linear trendline is plotted and statistical data shown to the right of the panels (N= number of points, SD = Standard Deviation). a) 1979-1983, an epoch of accretion; b) 1982-1988, an epoch of little change; c) 1988-2000, an epoch of erosion; d) 1979-2000, the entire data set.

I also measured the location of the high tide line during the tidal cycle prior to the time of measurement. This may be a more accurate determination of where the shoreline was in relationship to the same stage of the tide. I could never know where the shoreline was at low tide (unless low tide occurred at the measurement time) but, by locating the strand line, I could usually see where the shoreline had been at high tide. Figure 21 plots these data. The beach prograded 83.6 ft (25.5 m) during the first epoch, at a rate of 18.3 $ft.yr^{-1}$ (5.6 $m.yr^{-1}$ ). In the next epoch the shoreline remained nearly stable over the six years. In the ensuing 12 years the shoreline lost 11.7 ft (3.5 m) or at a rate of 0.4 $ft.yr^{-1}$ (0.1 $m.yr^{-1}$ ). Note that $R^2$ was virtually zero for these periods. Over the entire period, the shoreline eroded 39.1 ft (11.9 m) or 1.7 $ft.yr^{-1}$ (0.5 $m.yr^{-1}$ ), most of this lost from the sand stored on the beach after Hurricane Allen. Interestingly, the shoreline was at almost exactly the same location at the end of June 2000 as it was in 1979, a year before Hurricane Allen, resulting in essentially no overall erosion in 21 years.

There is more significance in the dune growth data than in shoreline changes as Figure 22 shows. The top two panels are not strictly representative of dune growth because after Allen they were made in reference to artificial barriers put there to promote dune growth. Since Gilbert in 1988, however (the third epoch), the dunes at Gulf Shores and elsewhere in the study site have been growing. A total change of 35 ft (10.7 m), or 1.6 $ft.yr^{-1}$ (0.5 $m.yr^{-1}$) has taken place (third panel, Fig. 22) with notable erosional events in 1996 and 1998. The full period (bottom panel) dune growth (noting the caveats above) of 95.1 ft (29.0 m) occurred essentially post-Allen (a rate of 4.3 $ft.yr^{-1}$ or 1.3 $m.yr^{-1}$. As with shoreline erosion, the present dune line is close to what it was just prior to Allen. How has this affected the width of the beach itself at Gulf Shores? Figure 23 shows how the beach widened in the first epoch at the considerable rate of 31.3 $ft.yr^{-1}$ (9.6 $m.yr^{-1}$). The trend line fits with an $R^2$ value of 0.56 (top panel). The beach narrowed at the rate of 5.5 $ft.yr^{-1}$ (1.5 $m.yr^{-1}$ ) in the ensuing six years but, in the next twelve years, the narrowing diminished and, in the past two years, has shown signs of widening again. Overall, the beach narrowed by 141.7 ft (43.1 m) following its growth after Hurricane Allen (bottom panel).

### 5.4 Summary of changes at Gulf Shores

Hurricane Allen in August 1980 eroded the dunes at Gulf Shores back to the condominium wall, some 141 ft (43 m). The presence of the condominium doubtless aided this erosion, as can be seen from the high altitude aerial image taken shortly after the hurricane (Fig. 24, courtesy USGS). Dunes on either side of Gulf Shores were not eroded as much. Figure 24 illustrates the process that led to the changes seen during the next two decades. At several locations beside Gulf Shores, unvegetated dunes and places where dune vegetation had been disturbed, provided channels for the storm surge to penetrate deep into the main dune area. The storm was not powerful enough to breach the island and transport sand to the back bay, hence, sand from the dunes was stored on the beach and just offshore. The beach grew wider and continued to grow for the next three years as sand was redeposited on the shore-face. Two processes occurred simultaneously over the next several years: the dunes grew seaward and the shoreline eroded landward, resulting in a narrowing of the beach. Four storm events temporarily arrested these processes, Hurricane Gilbert in 1988 and Tropical Storms Josephine in 1996, and Charley and Frances in 1998. Hurricane Brett in August 1999 had little effect on Mustang Island Gulf Beach.

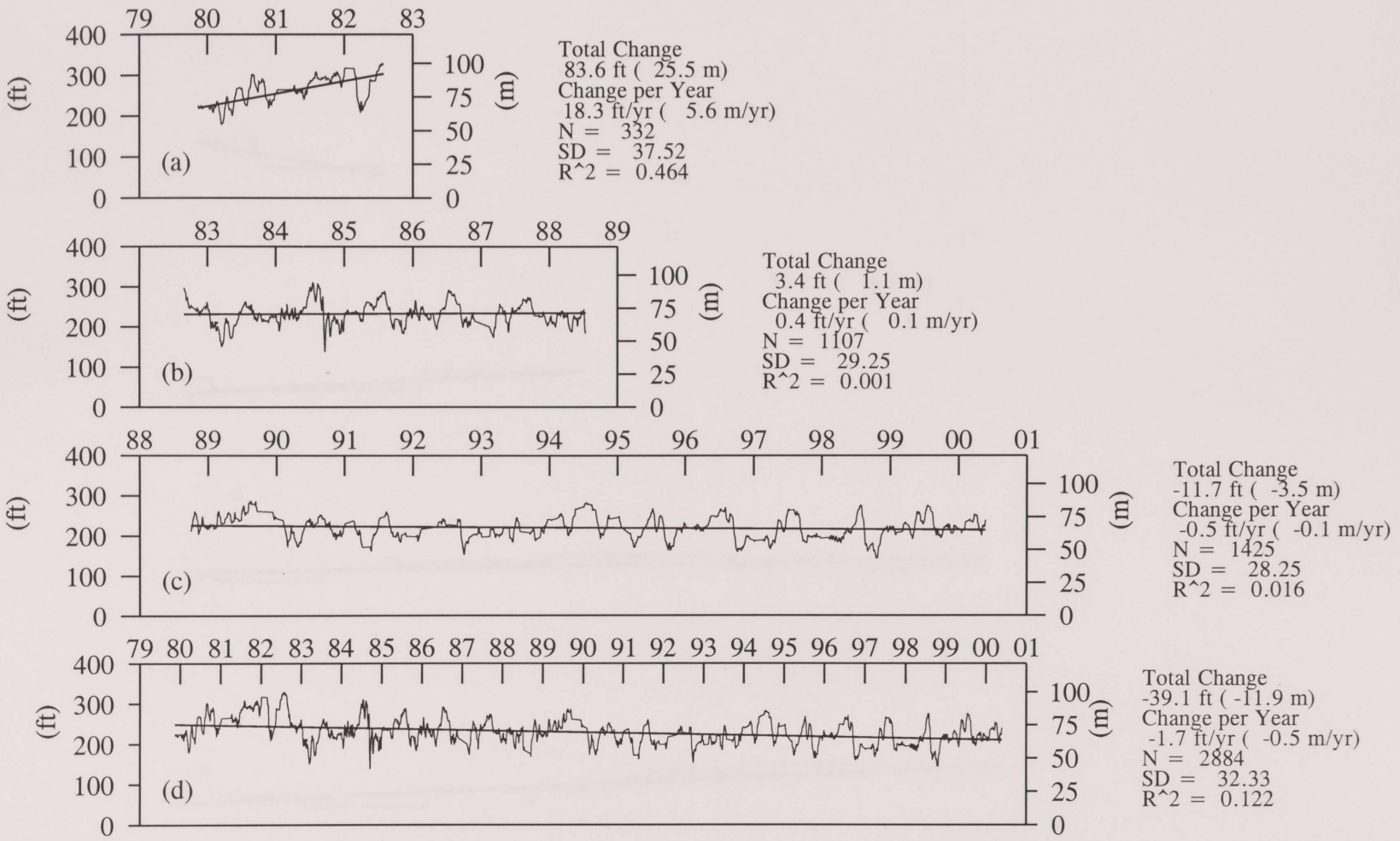



Figure 21. Erosion/accretion of shoreline (using location of the last high tide line) at Gulf Shores: 1979-2000. Each panel shows the location of shoreline relative to Gulf Shores Condominium wall facing the sea (zero on scale) for epochs of years with similar trends. The data has been smoothed with a 10-point running mean. The linear trendline is plotted and statistical data shown to the right of the panels (N= number of points, SD = Standard Deviation). a) 1979-1982, an epoch of accretion; b) 1982-1988, an epoch of little change; c) 1988-2000, an epoch of erosion; d) 1979-2000, the entire data set.

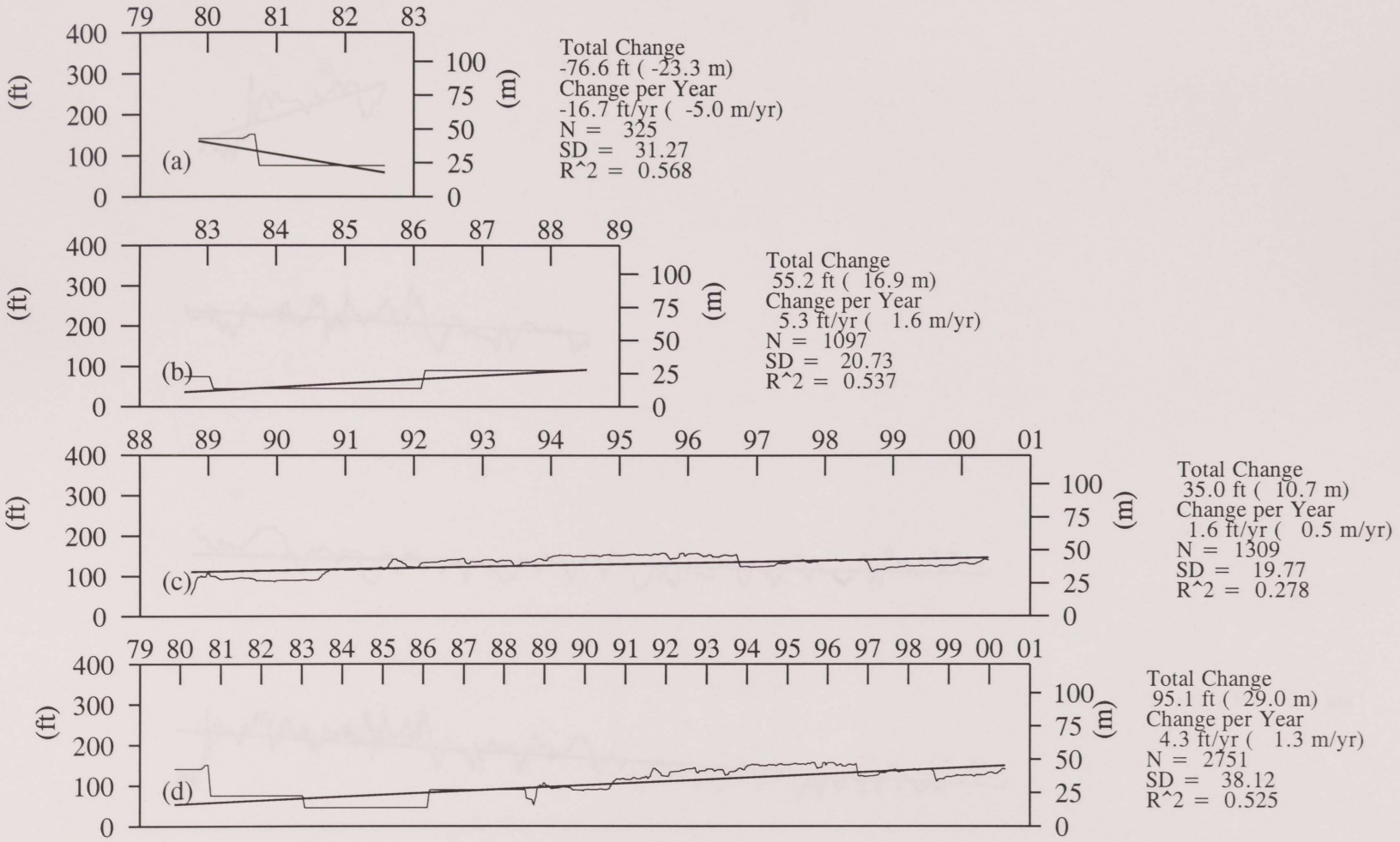



Figure 22. Erosion/accretion of dunes at Gulf Shores: 1979-2000. Each panel shows the location of shoreline relative to Gulf Shores Condominium wall facing the sea (zero on scale) for epochs of years with similar trends. The data has been smoothed with a 10-point running mean. The linear trendline is plotted and statistical data shown to the right of the panels (N= number of points, SD = Standard Deviation). a) 1979-1982; b) 1982-1988 (in a and b, the flat, stepped appearance reflects measurements to fixed fence lines); c) 1988-2000, an epoch of dune growth with erosional events; d) 1979-2000, the entire data set.

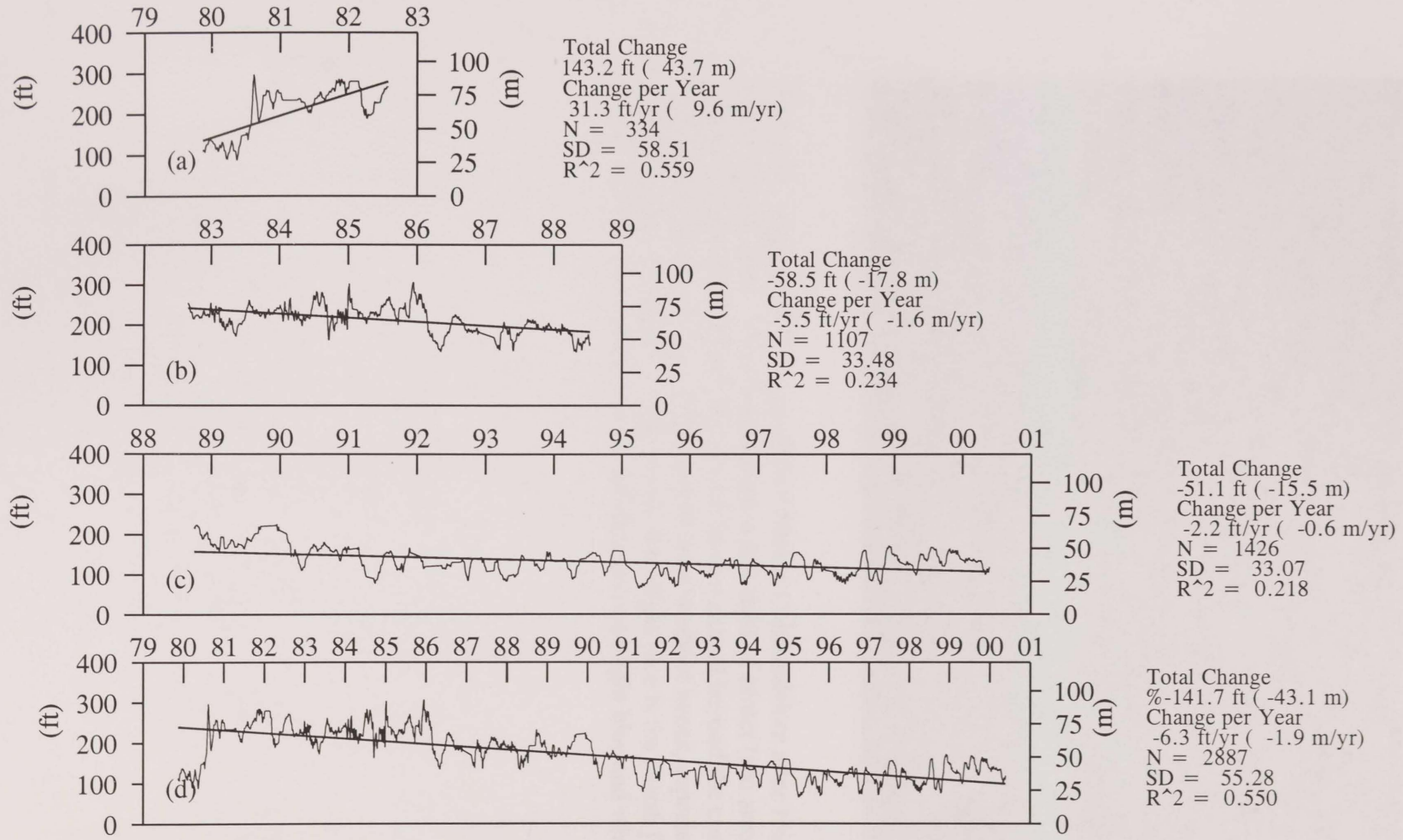



Figure 23. Changes in beach width at Gulf Shores: 1979-2000. Each panel shows the width of the beach from dune line to shoreline for epochs of years with similar trends. The data has been smoothed with a 10-point running mean. The linear trendline is plotted and statistical data shown to the right of the panels (N= number of points, SD = Standard Deviation). a) 1979-1982, an epoch of considerable accretion; b) 1982-1988, an epoch of narrowing of the beach; c) 1988-2000, an epoch when beach narrowing lessened and ultimately stopped; d) 1979-2000, the entire data set.

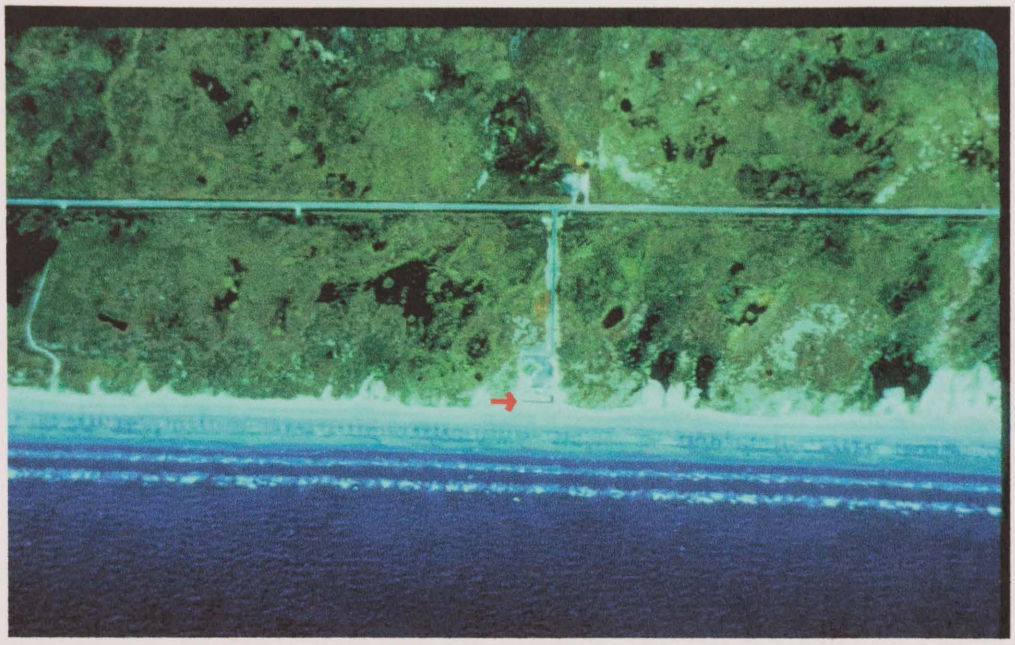


Figure 24. High altitude image of Gulf Shores Condominium after Hurricane Allen, August 1980. The condominium is just right of center (red arrow). Notice that the dunes either side of Gulf Shores extend beyond the condominium wall facing the sea. Note several dune washout zones, especially at extreme right. The beach is wide in this view (light blue is the swash [wet] zone). The old dune line is at the boundary between light blue and white.

## 6. BEACH CHANGES AT OTHER LOCATIONS

This data set extends from 1983 through the present with a change in September 1988 after Hurricane Gilbert. Prior to Gilbert two measurements were made at one-mile intervals from, and including, Gulf Access Road #1. Beach widths were measured from shoreline to high tide line and then to the dune line. Post-Gilbert, a third measurement to a datum post was added. The schematic is shown in Figure 25. As with the measurements at Gulf Shores, both the transverse and lateral locations of these mile locations has changed on occasion and adjustments to the data made accordingly. The present locations of the Mile 0 to 7 measuring sites are given in Table 4, page 16. Figure 26 shows the orientation of the sites with respect to the true shoreline and the location of the high tide line and dune line on a day in winter when the beach was at its widest. The vertical exaggeration is approximately 100:1. The present location of facilities with beach access is also shown with respect to distance (their location with respect to the shoreline is only schematic).

### 6.1 Changes by year

Figures 27 through 44 represent the location of the shoreline and high tide line relative to the dunes at each mile and include Gulf Shores data at "Mile G". After Gilbert in 1988 the figures are plotted relative to the fixed datum post and all measurements are absolute and show erosion tending landward and accretion, seaward. At all locations, and for the entire length of the series from 1983 (except Mile 0), the width of the beach is also true, as shown by the region between the dark shading and the shoreline. The light shaded area, the swash zone, is also a true measurement. In general, the dune line should be comparatively smooth with time, except when there was an abrupt erosional event (the dune line is shown as unvarying prior to Hurricane Gilbert as that was the reference, and also for several years at Mile 0, to be explained later). Occasional suspicious-looking indents or bulges appear in the dune line. A total of 53,885 individual measurements make up the data plotted in Figures 27-44 and, although much time was spent in correcting these, a few irreconcilable outliers remain in the data. On several occasions, the high tide line is shown landward of the dune line. These are not errors, as wave runup during storms can penetrate low areas of the dunes without eroding them. At the access road the water advances up the roadway itself during a storm due to the low elevation of the road bed and surrounding apron. The same data gaps as at Gulf Shores are also present here. Thin lines connect the various shaded areas between gaps. Refer to section 4 for details on various events responsible for the changes seen in these figures.

#### 6.1.1 Changes at Access Road #1

Access Road #1 (Fig. 45) has the widest beach of the survey transect. Because the city is constantly grading the beach opposite the access road, the dunes bordering the entrance form a wide apron and are distant from the axis of the road where the measurements are made. It is therefore difficult to gage the location of the dune edge. Prior to 1995, I only measured to the datum post but, because the dunes were being artificially built, I started sighting on the dunes to the south to add a dune line measurement in 1995. This accounts for the sudden change in the dark shaded area in Figure 45. Notice the rapid accretion of the dunes and the subsequent narrowing of the beach. Notice also that this is a region of shoreline accretion.

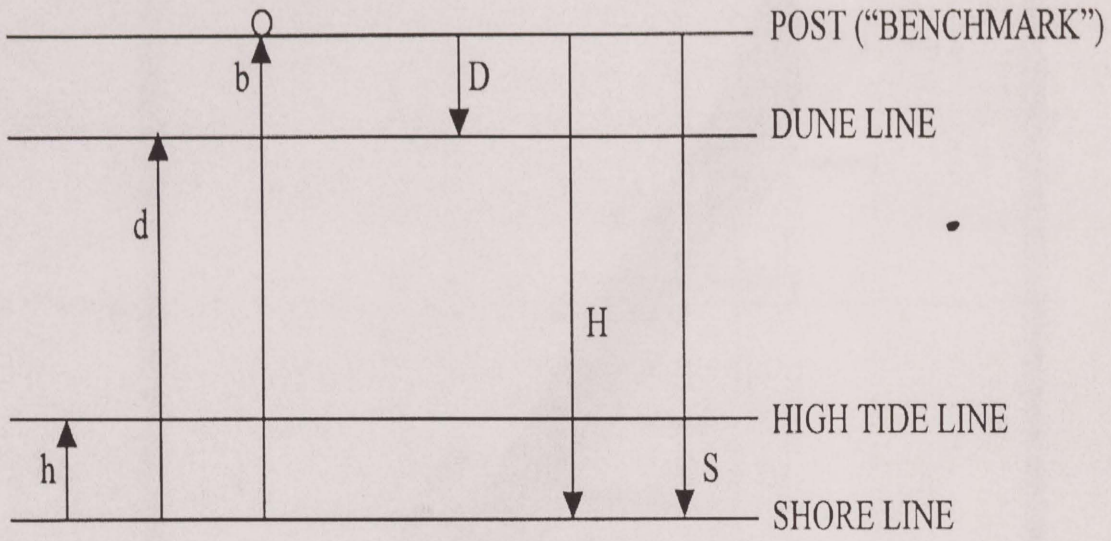



Figure 25. Schematic of measurements made at Miles 0–7 and calculation of distances used in monitoring erosion/accretion. Lower case, actual measurements made at each observation; upper case, calculated distances. Key: h=shore line to high tide line; d=shoreline to dune line; b=shoreline to benchmark; S=location of shoreline (b); H=location of high tide line (b-h); D=location of dune line (b-d).

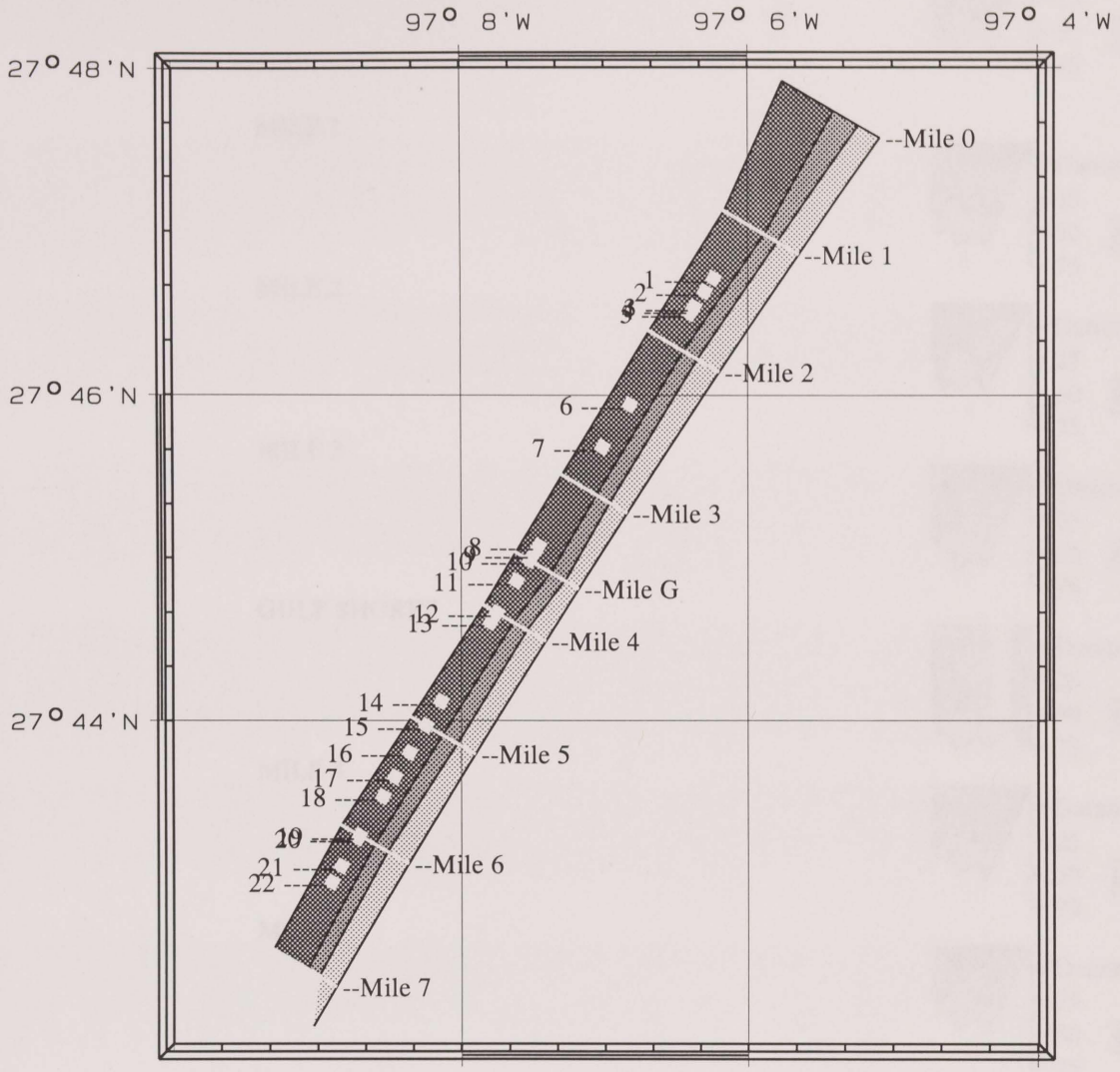



Figure 26. Location of shoreline, high tide line, dunes and beach-front buildings on January 20, 2000. Plan view is in correct geographical orientation. Building locations are correct in relationship to their distance along the beach from Access Road #1 (Mile 0) but not in their location relative to the dunes. Beach width measuring sites are shown as lines perpendicular to the shoreline. Darkest shading represents the dunes, medium shading is the beach width to the high tide line, lightest shading is the swash zone, all vertically exaggerated.

Key to buildings: 1-Walkway, 2-BeachWalk1 walkway, 3-BeachWalk2 walkway, 4-El Cortez walkway, 5-Casadel walkway, 6-Flato House, 7-New blue-roofed house, 8-La Mirage walkway, 9-Mariner s Watch walkway, 10-Gulf Shores, 11-Mustang Towers walkway, 12-Mustang Beach Club walkway, 13-Port Royal walkway, 14-Sandpiper walkway, 15-Seagull walkway, 16-Lost Colony, 17-Religious retreat walkway, 18-Hawn walkway, 19-First Private House walkway, 20-Second Private House walkway, 21-Admiral s Row walkway, 22-Mayan Princess walkway.

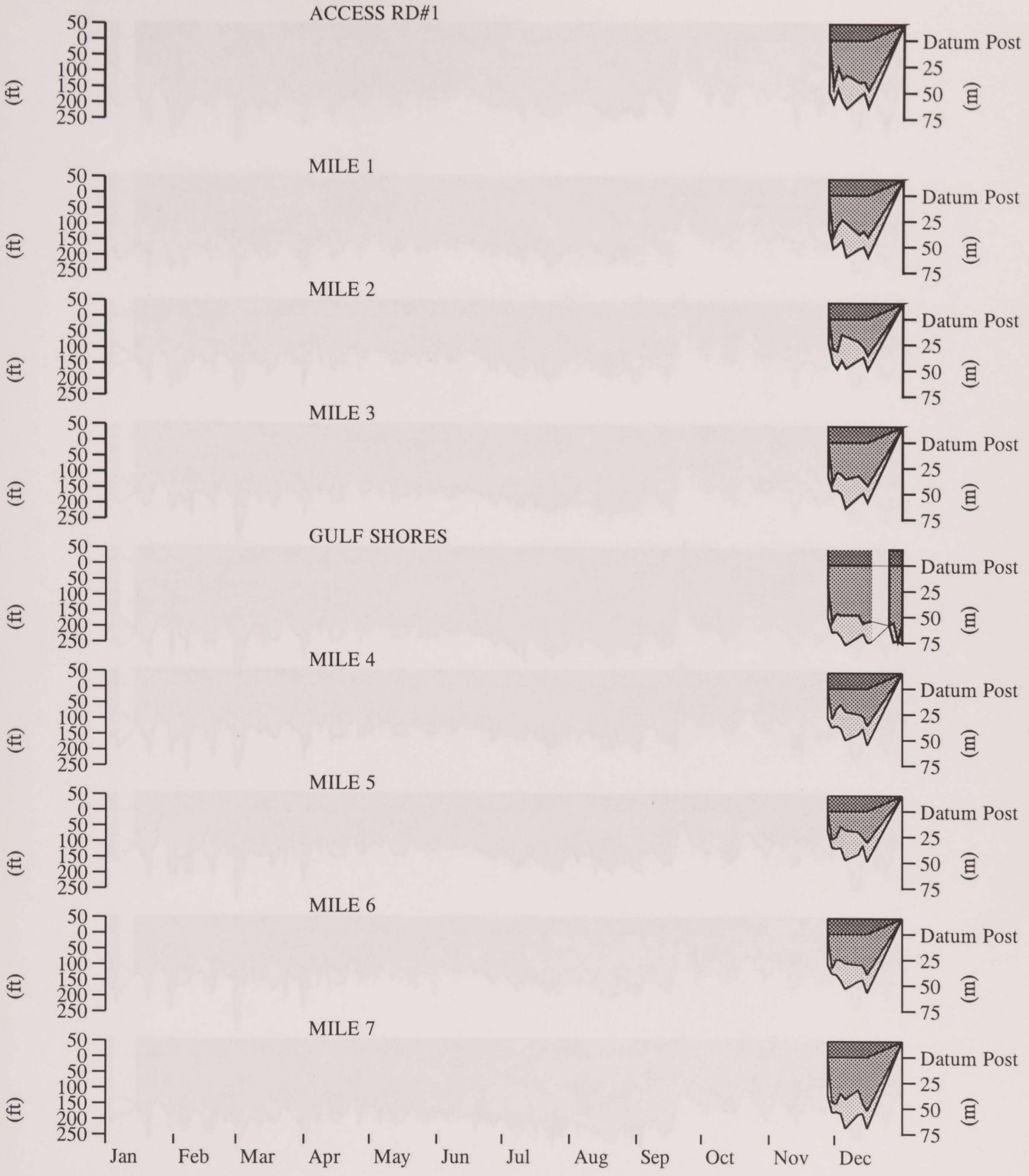



Figure 27. Location of dune line, high tide line and shoreline: 1983. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here (separate measurement of dune location did not start until 1988).

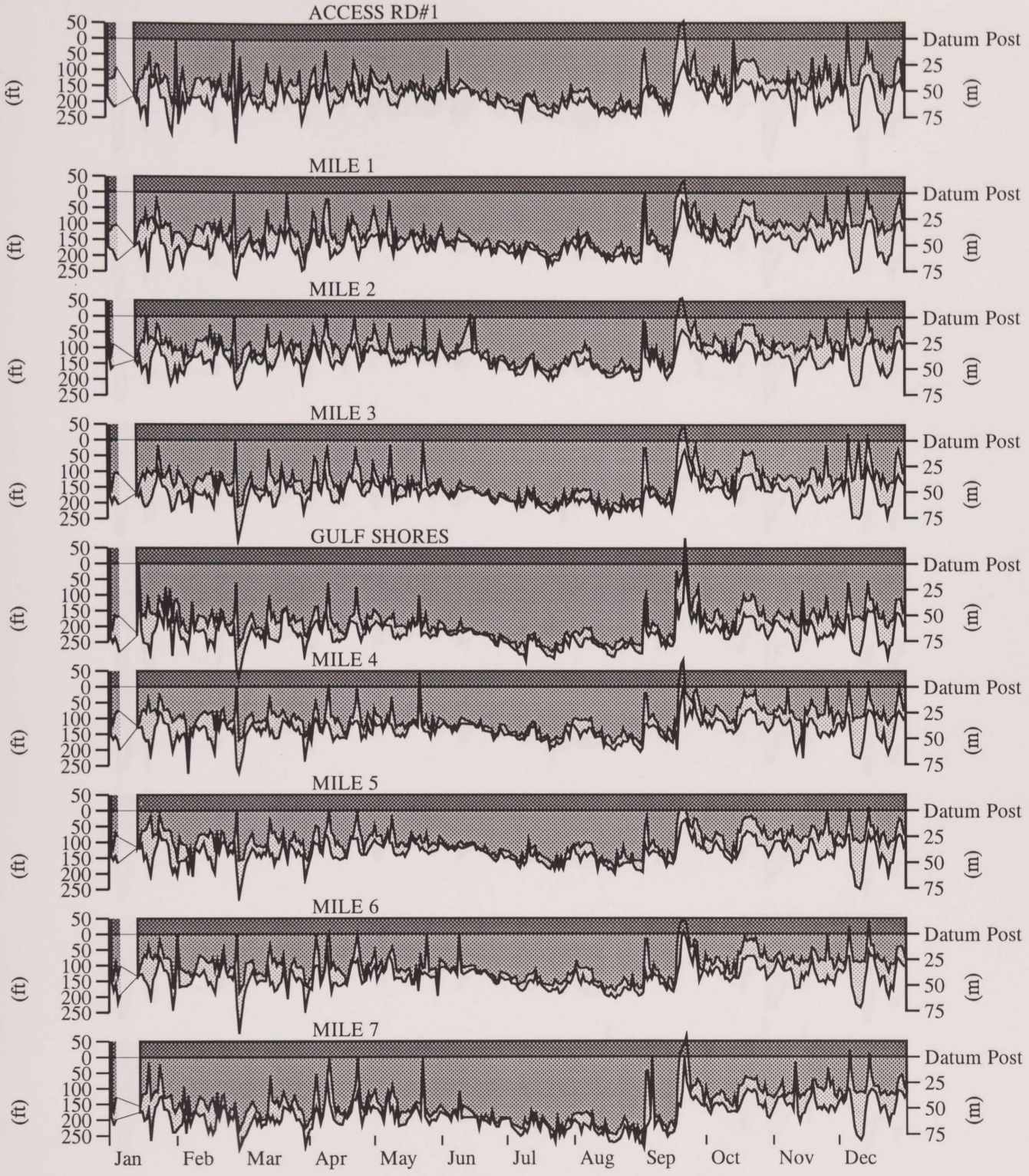



Figure 28. Location of dune line, high tide line and shoreline: 1984. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here (separate measurement of dune location did not start until 1988).

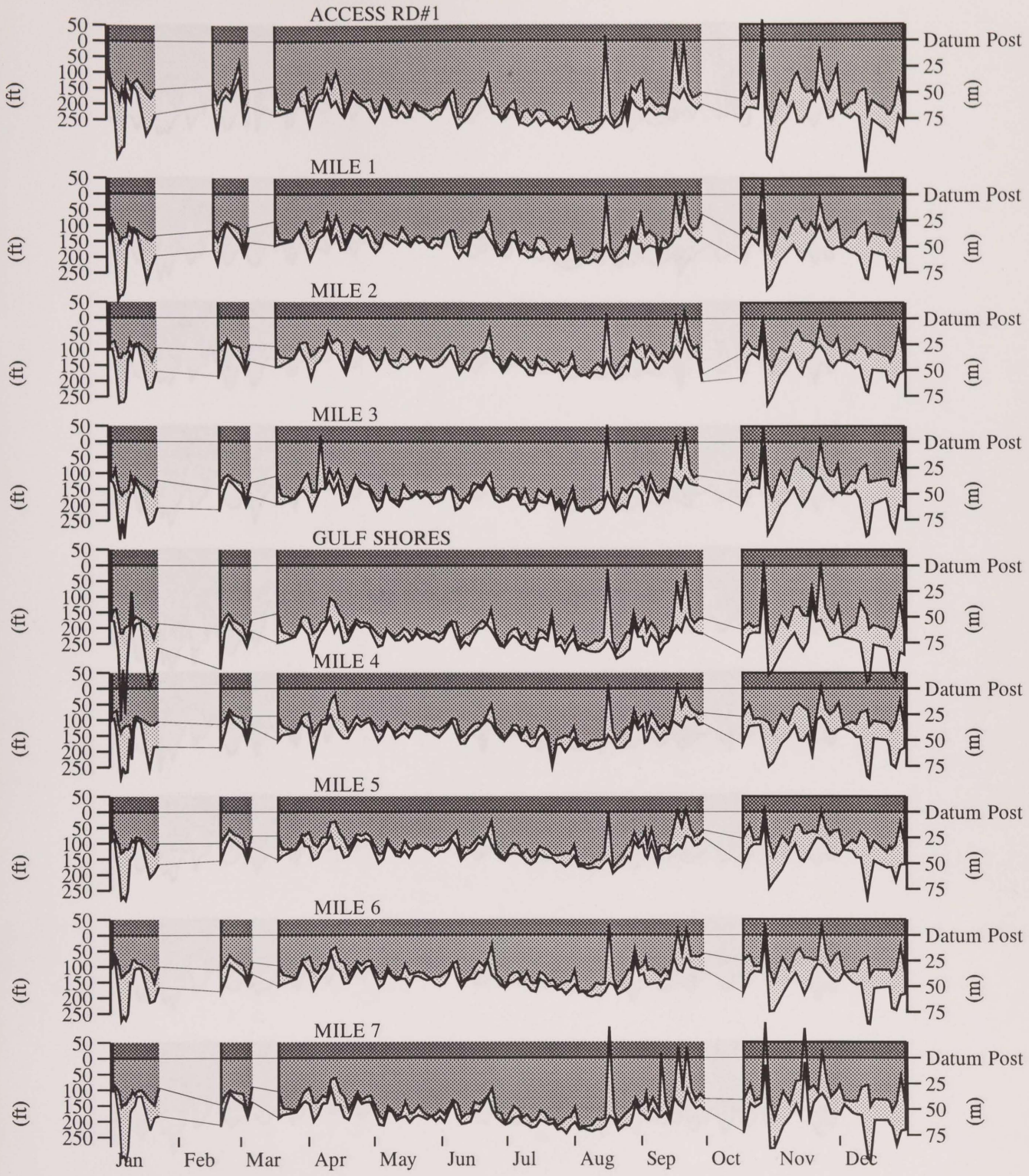



Figure 29. Location of dune line, high tide line and shoreline: 1985. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here (separate measurement of dune location did not start until 1988).

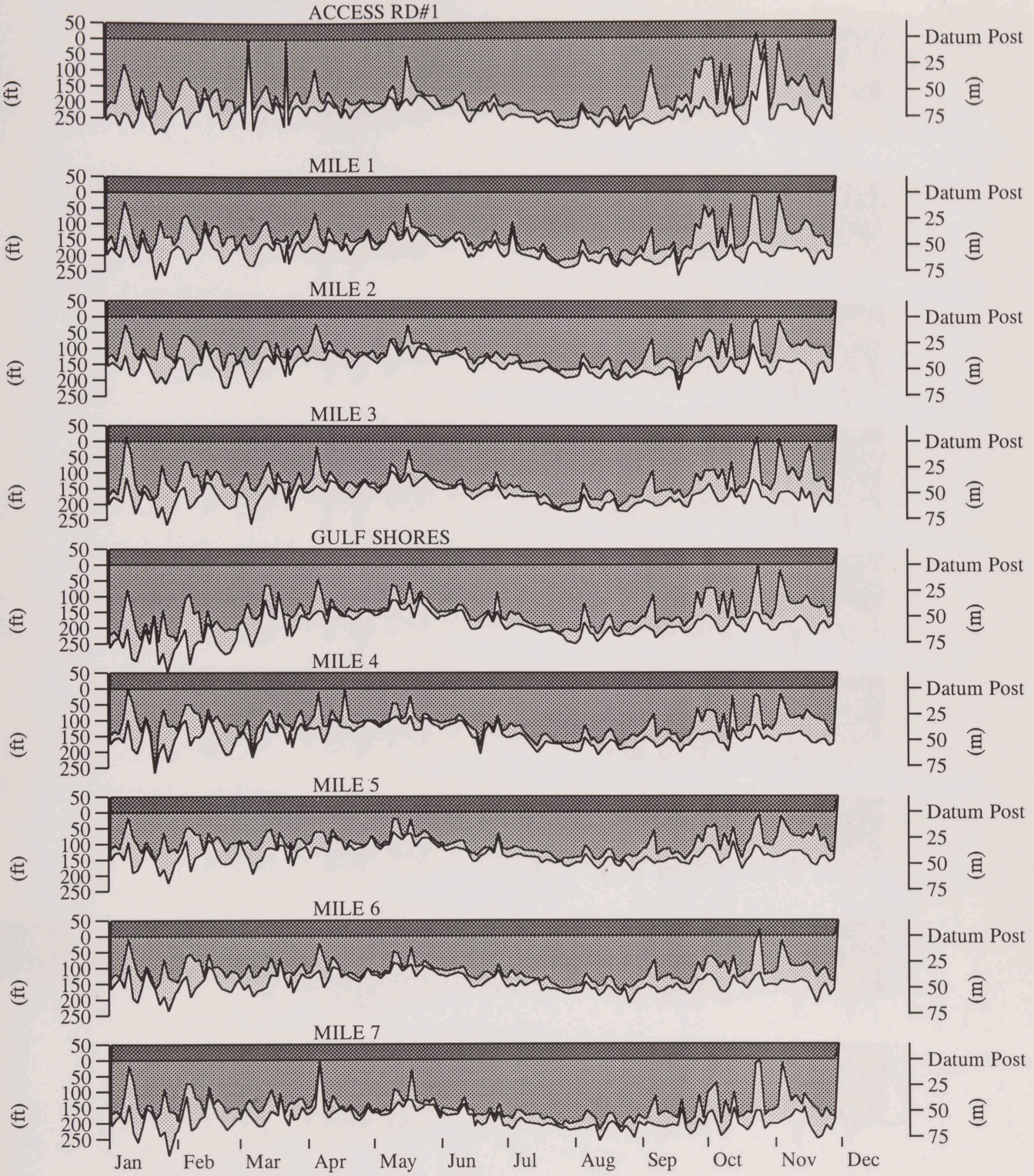



Figure 30. Location of dune line, high tide line and shoreline: 1986. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here (separate measurement of dune location did not start until 1988).

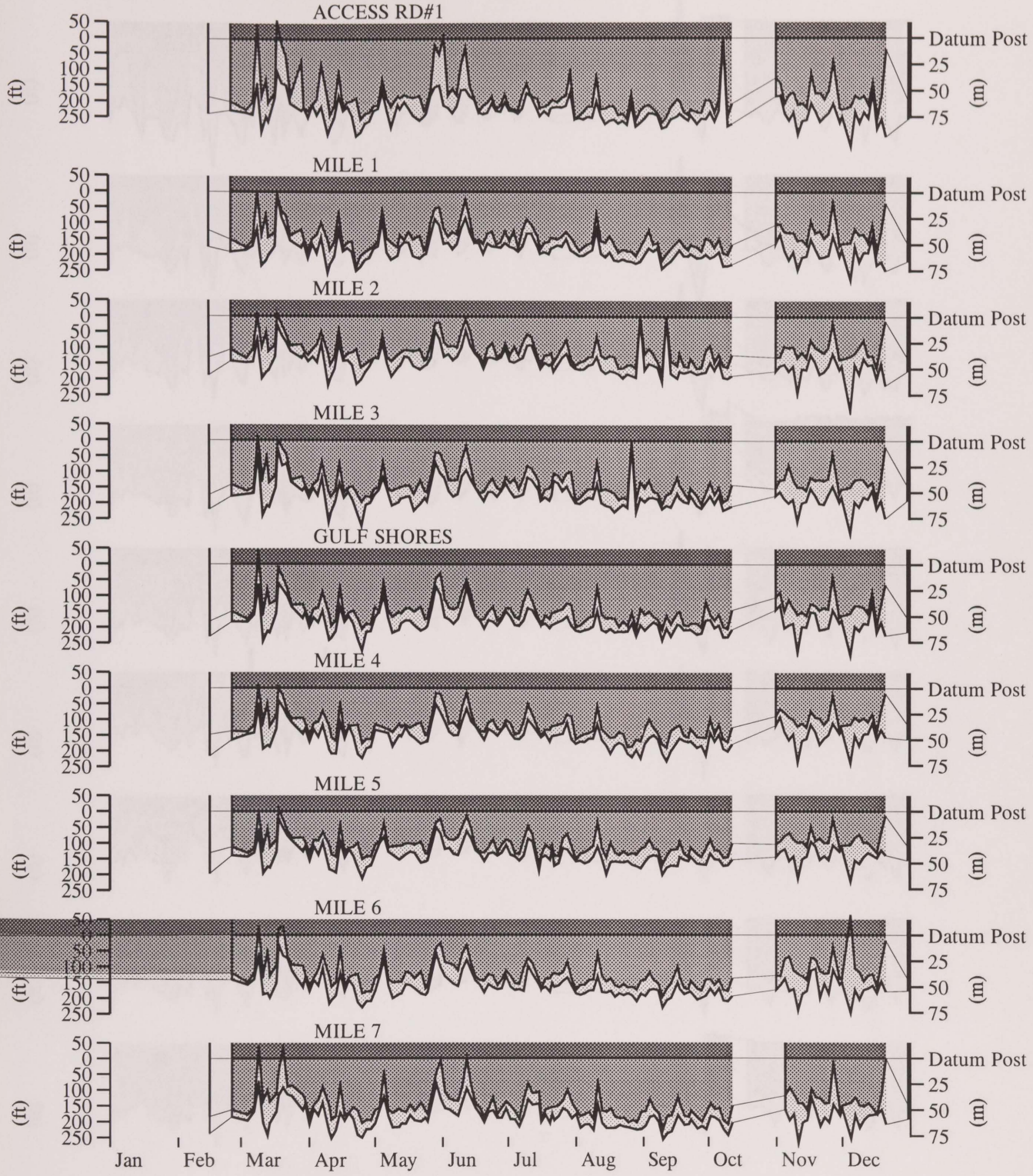



Figure 31. Location of dune line, high tide line and shoreline: 1987. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here (separate measurement of dune location did not start until 1988).

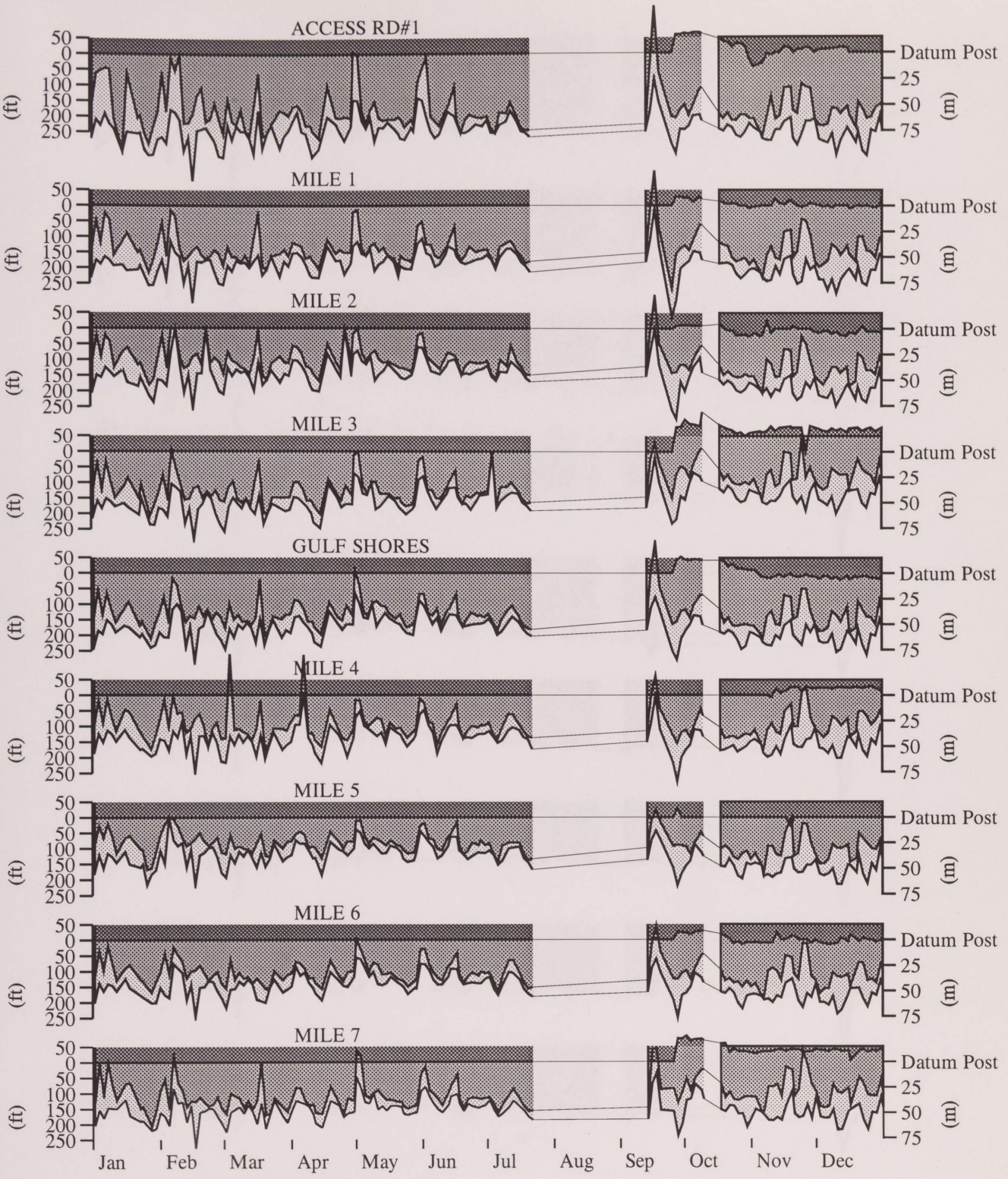



Figure 32. Location of dune line, high tide line and shoreline: 1988. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores. Dune line coincident with datum post here until separate measurements of dune location started in September.

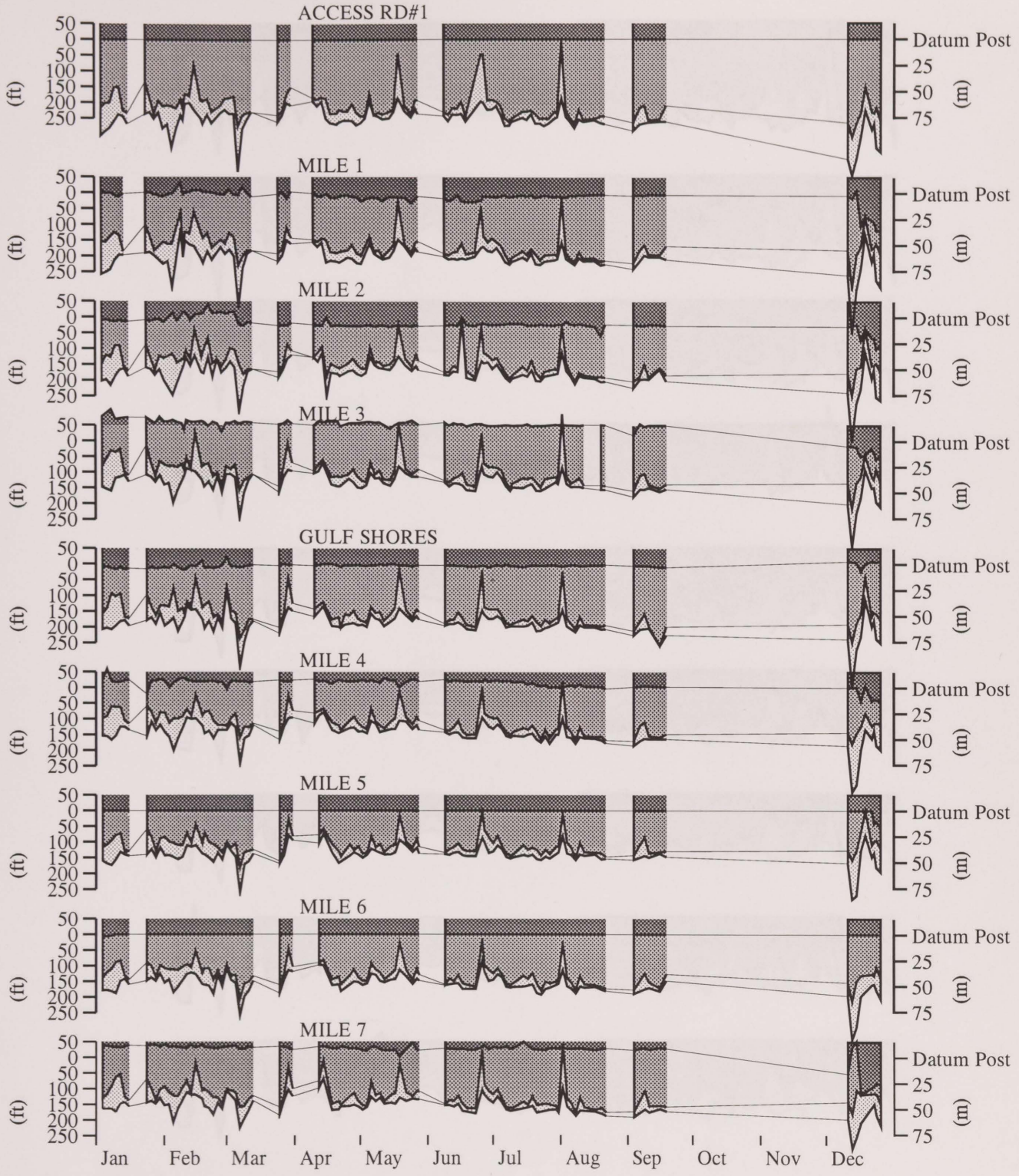



Figure 33. Location of dune line, high tide line and shoreline: 1989. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

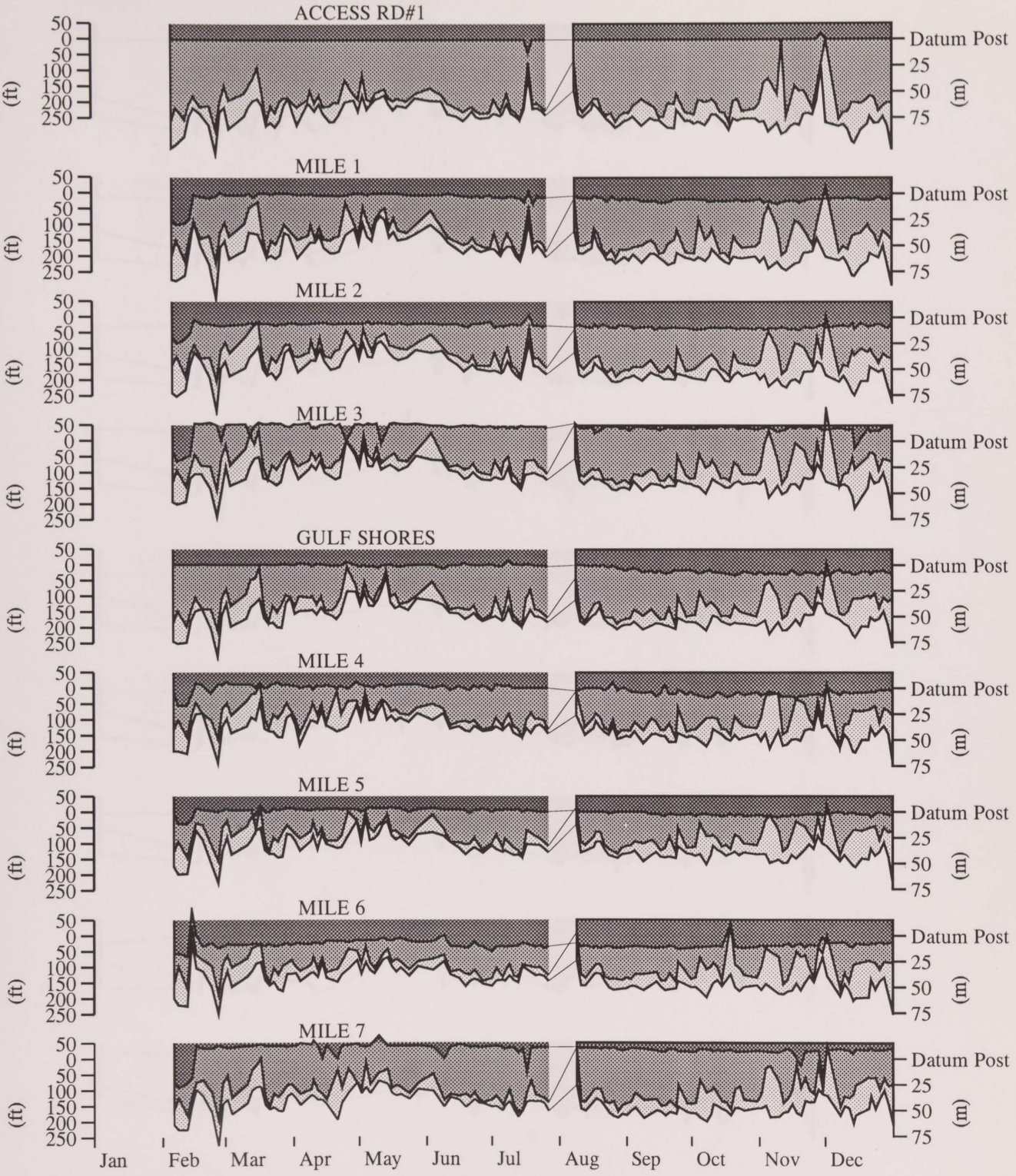



Figure 34. Location of dune line, high tide line and shoreline: 1990. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

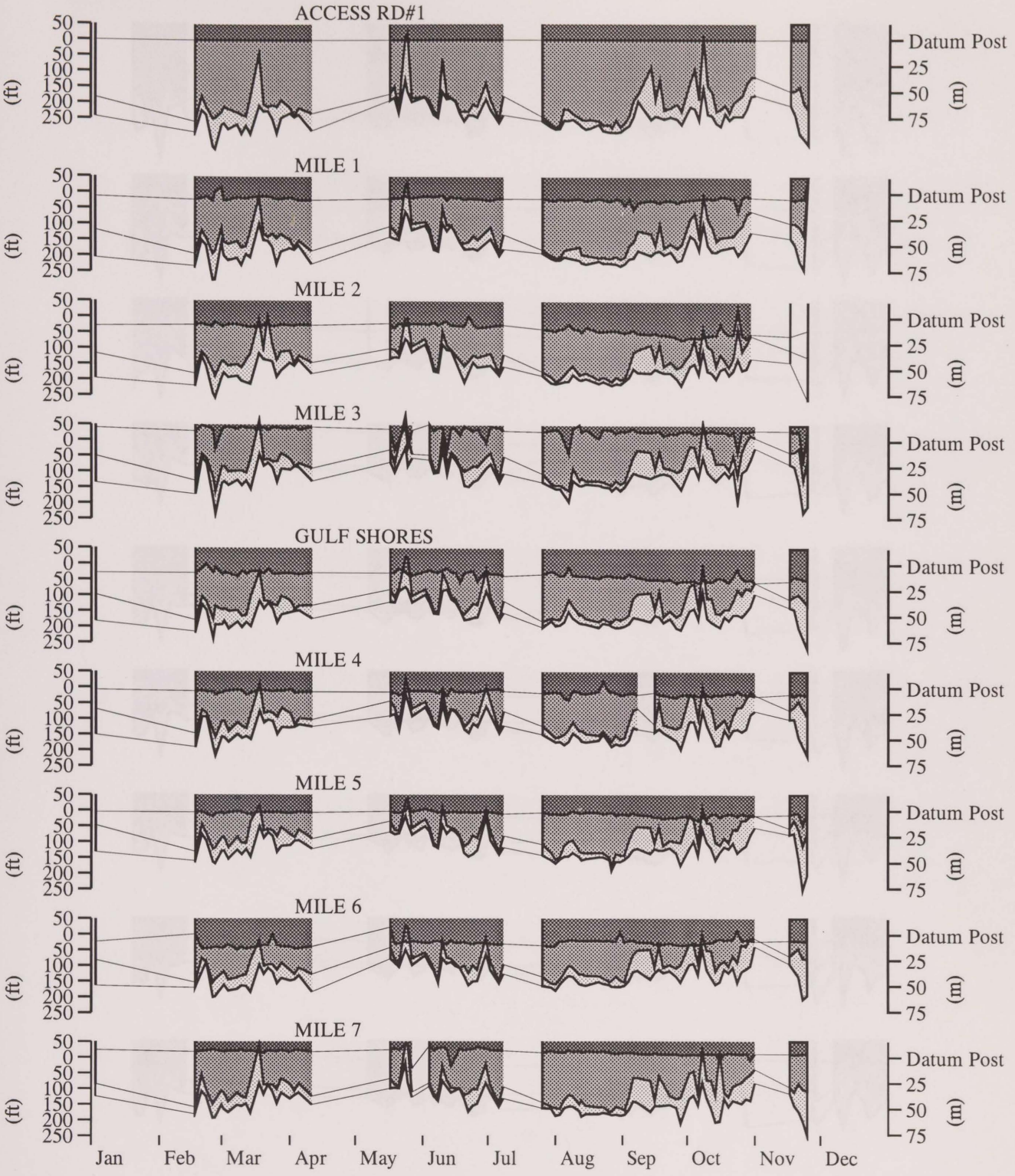



Figure 35. Location of dune line, high tide line and shoreline: 1991. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

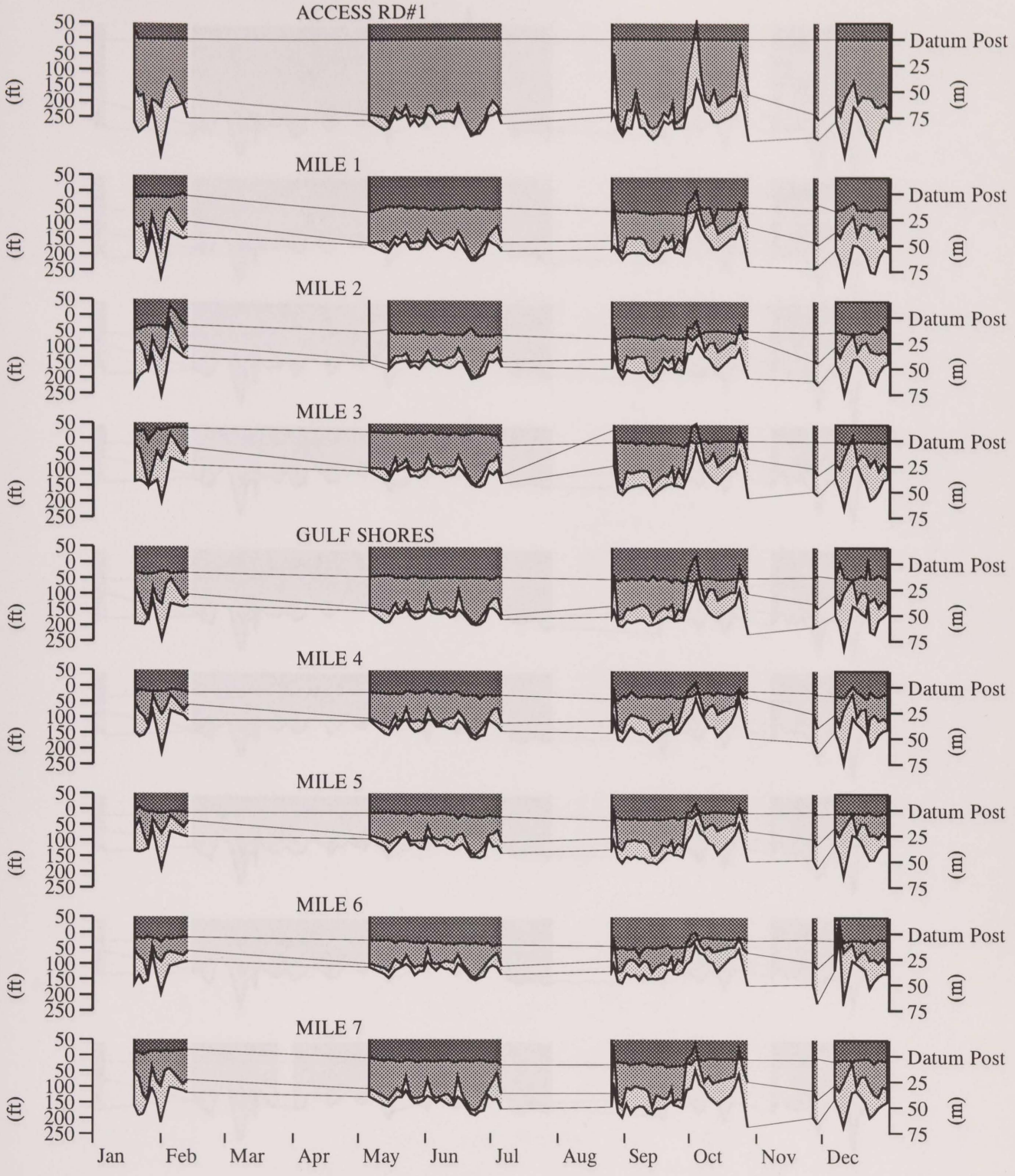



Figure 36. Location of dune line, high tide line and shoreline: 1992. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

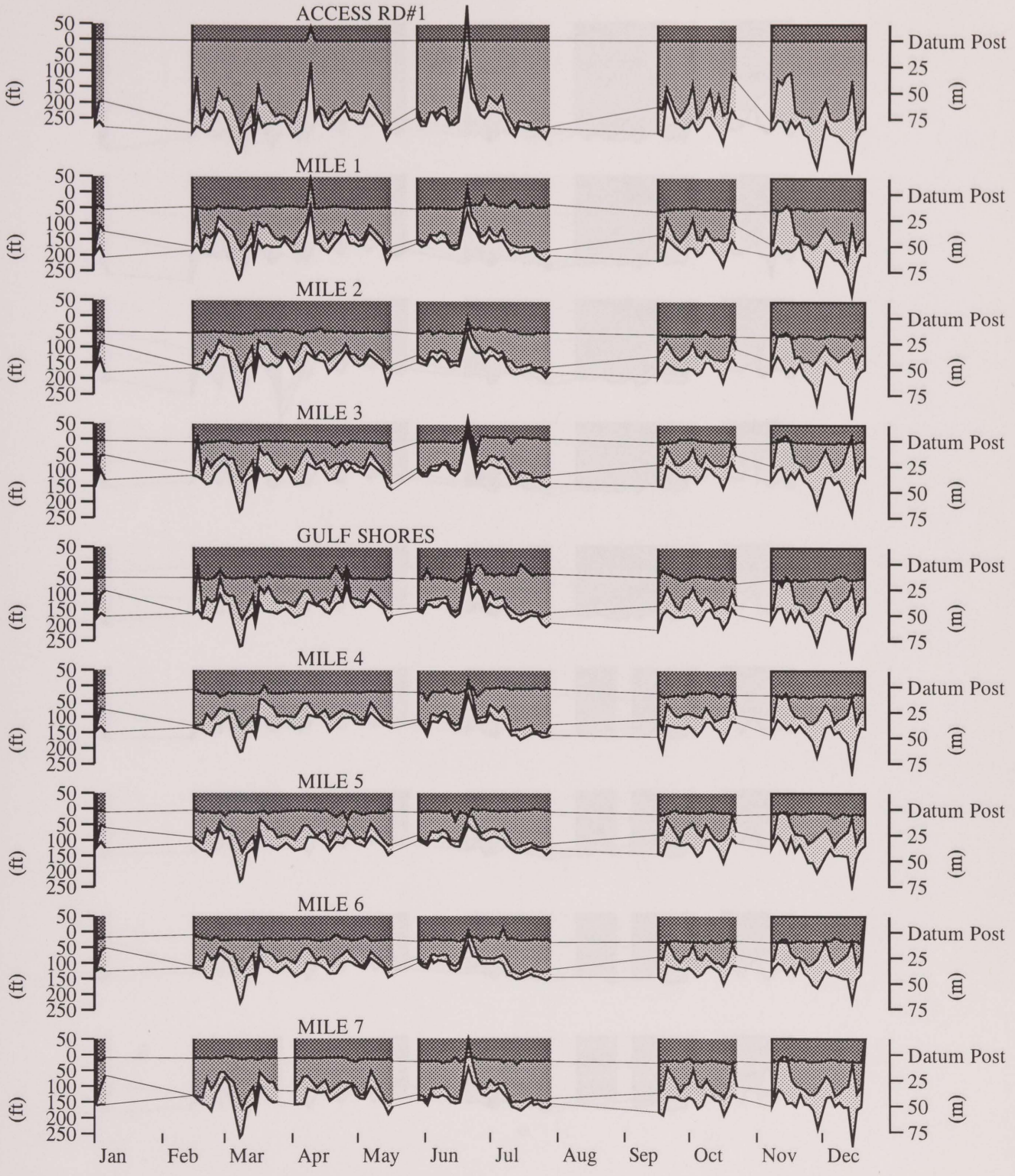



Figure 37. Location of dune line, high tide line and shoreline: 1993. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

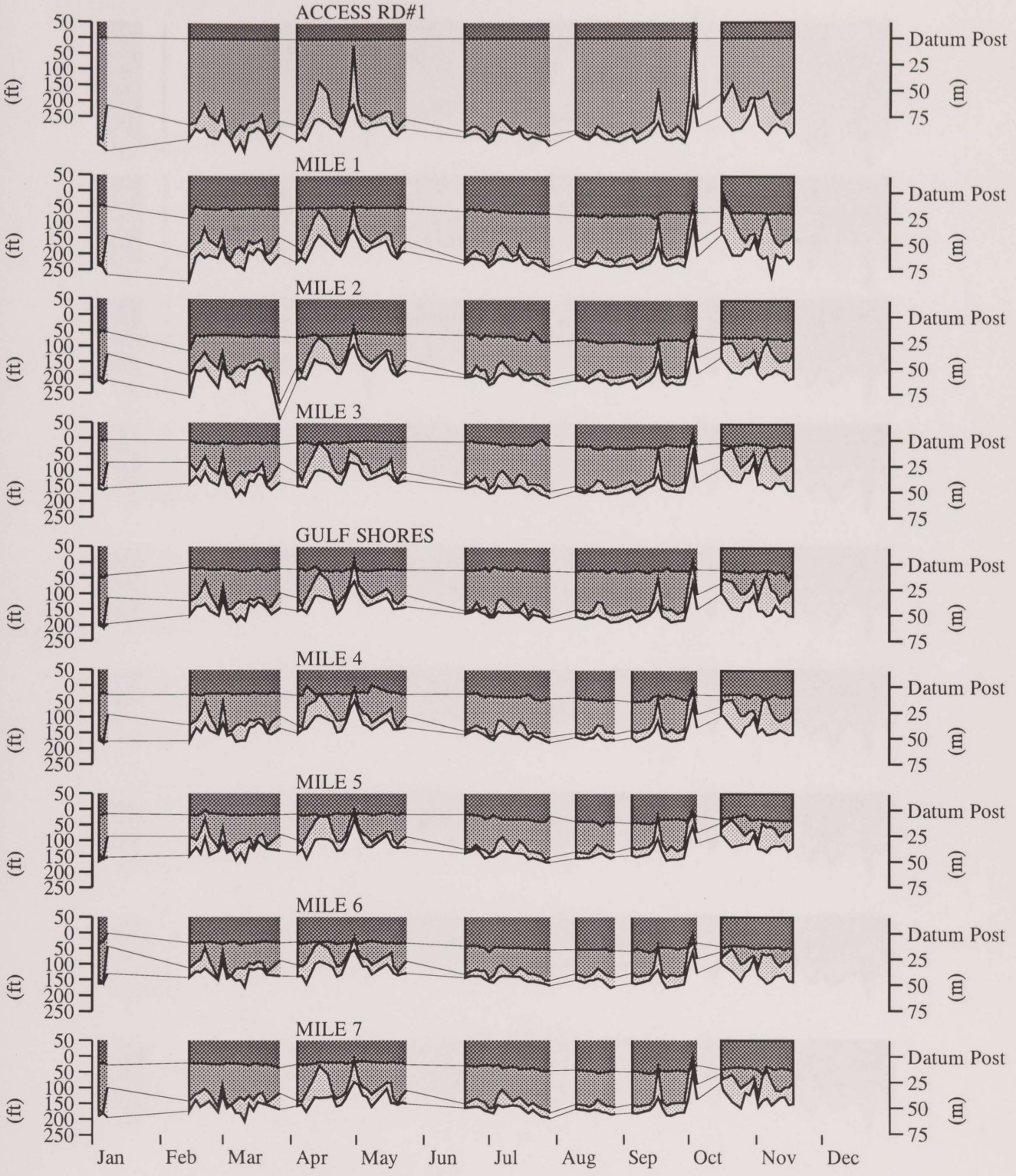



Figure 38. Location of dune line, high tide line and shoreline: 1994. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

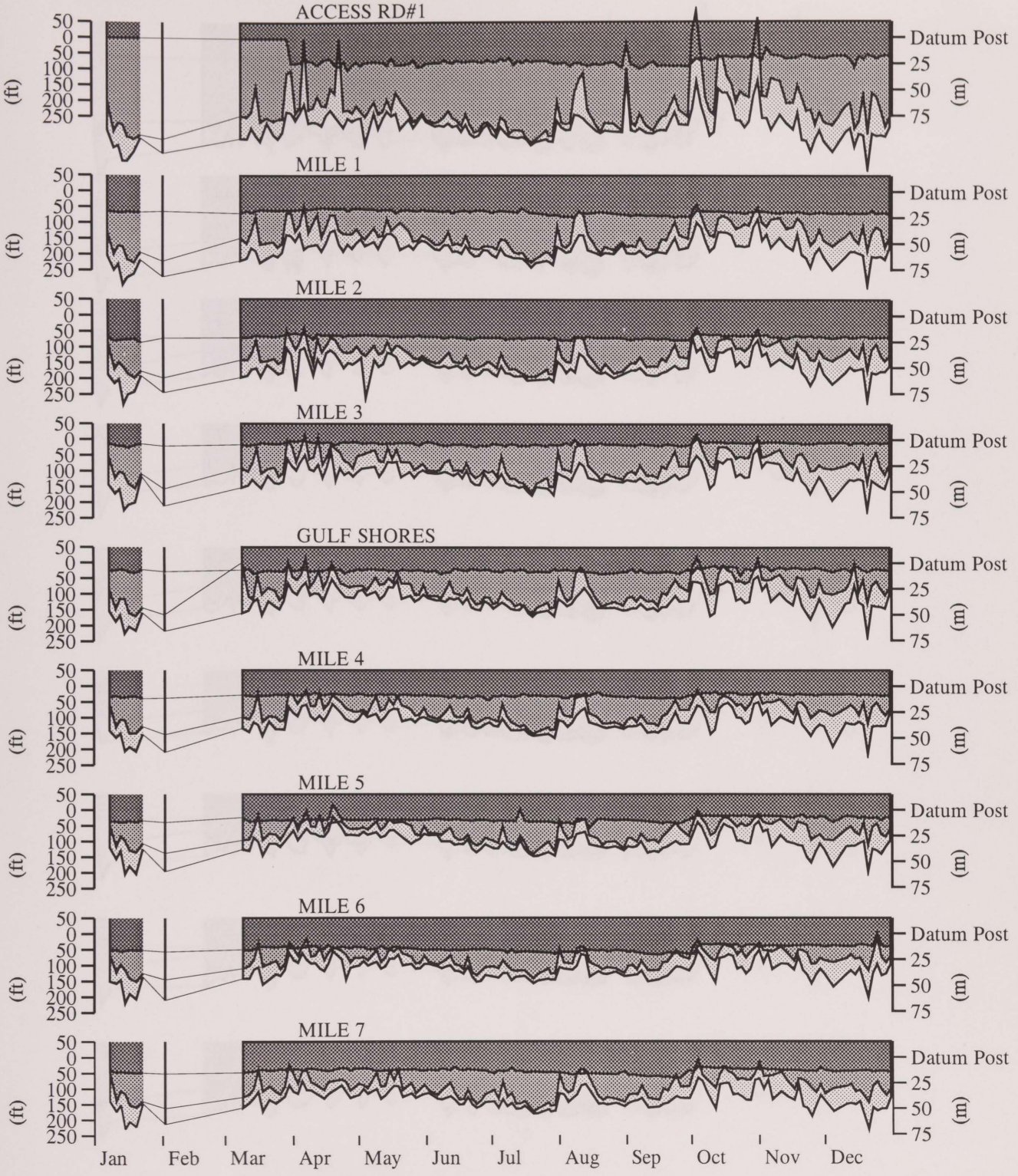



Figure 39. Location of dune line, high tide line and shoreline: 1995. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

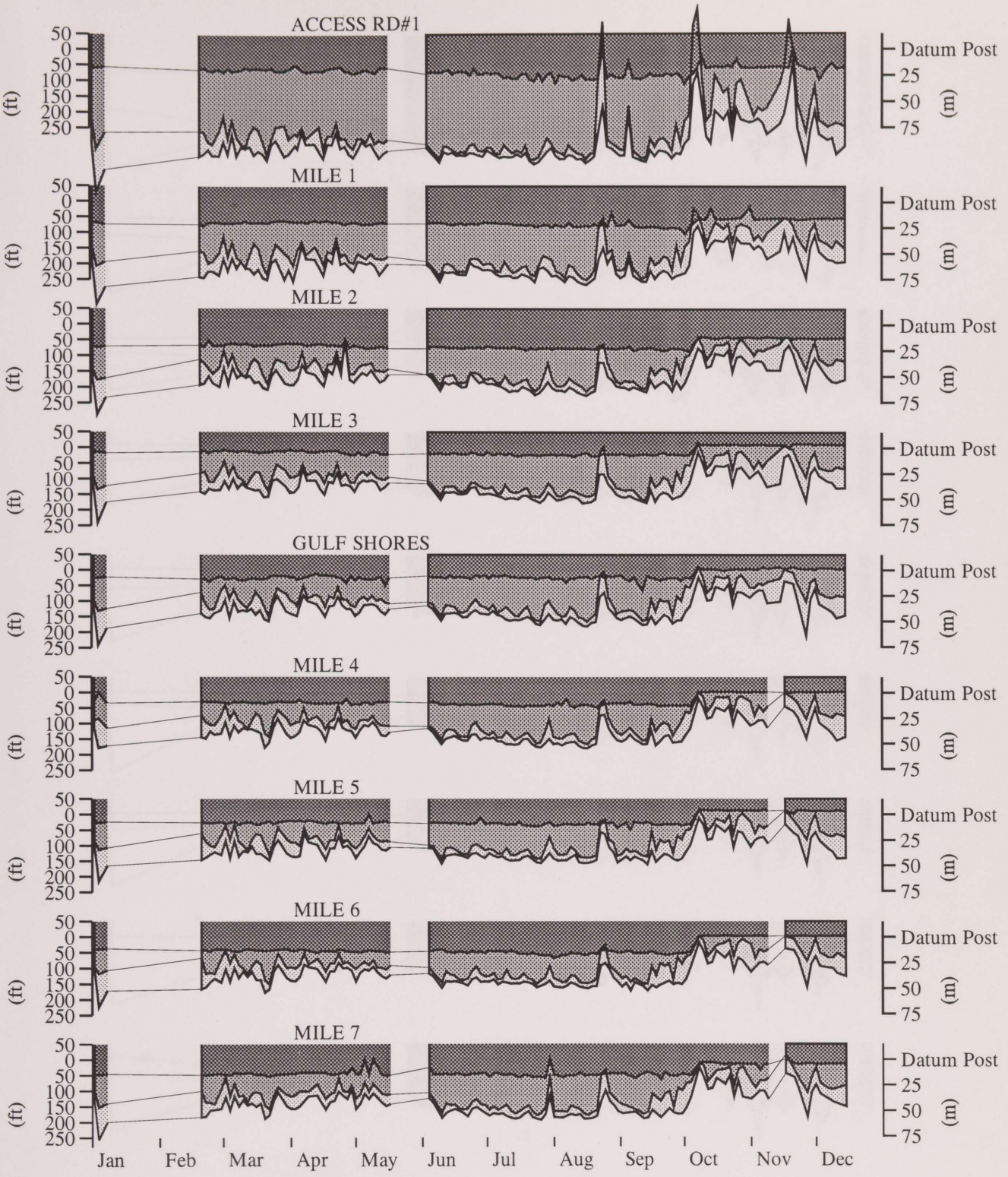



Figure 40. Location of dune line, high tide line and shoreline: 1996. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

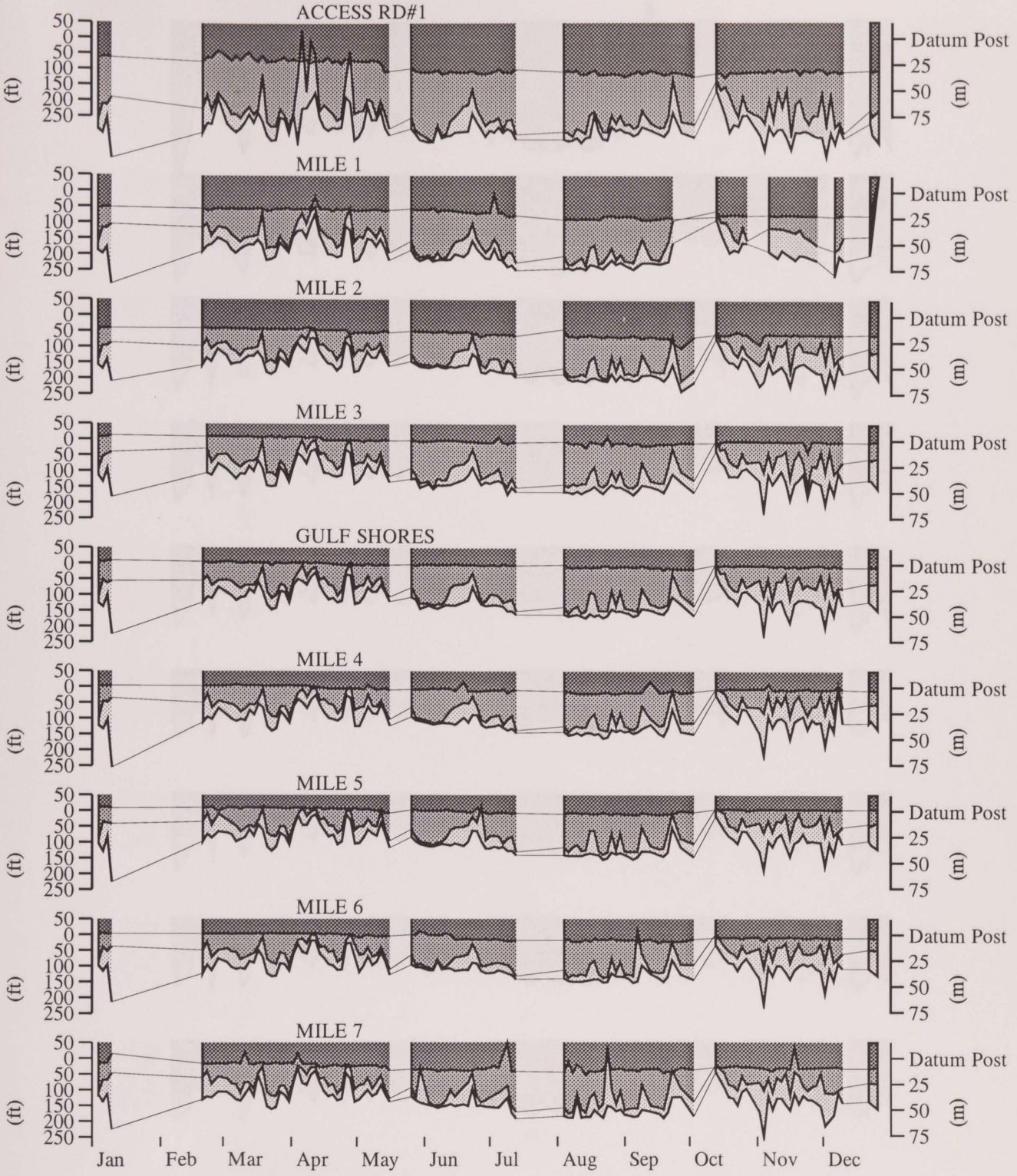



Figure 41. Location of dune line, high tide line and shoreline: 1997. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

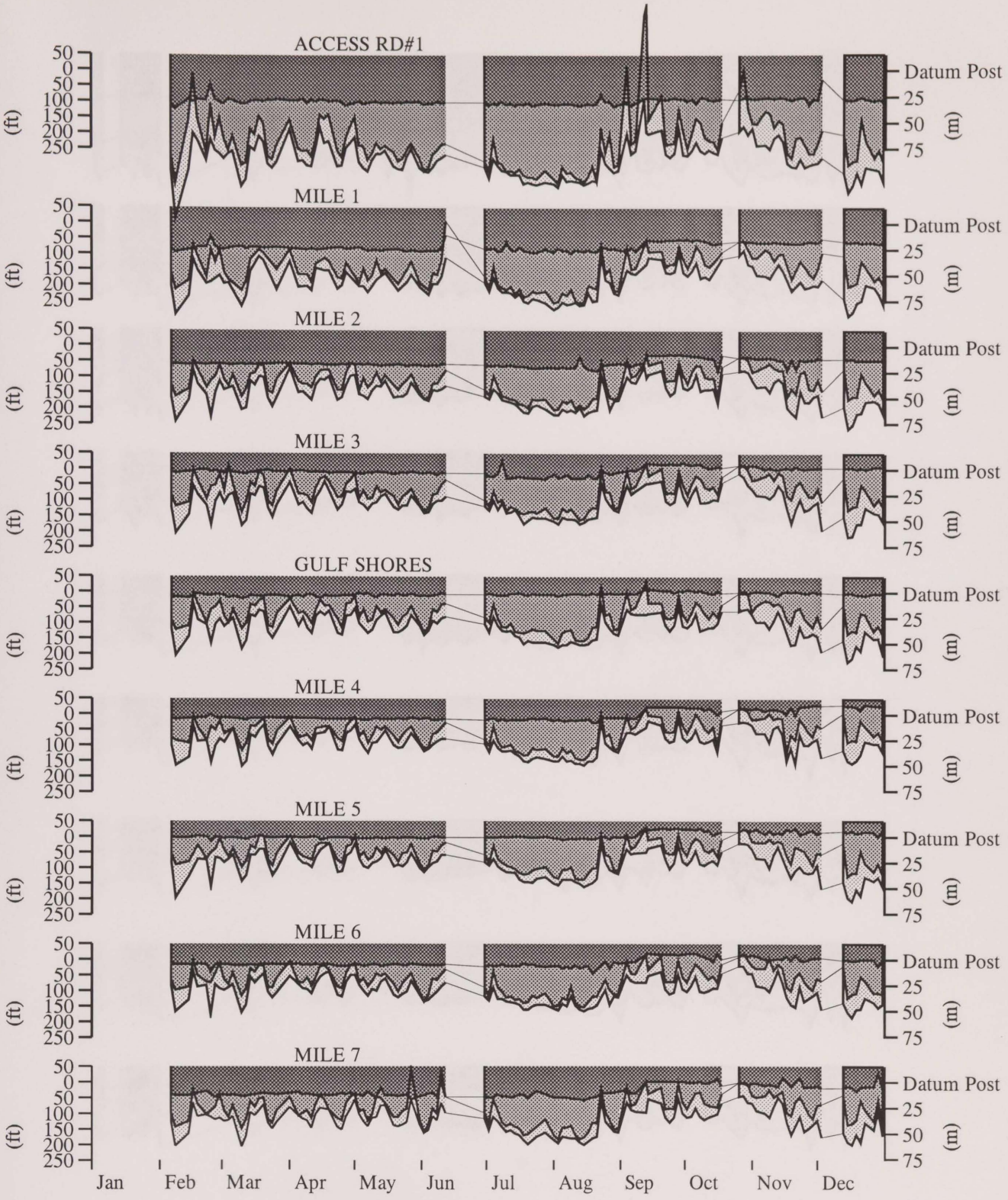



Figure 42. Location of dune line, high tide line and shoreline: 1998. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

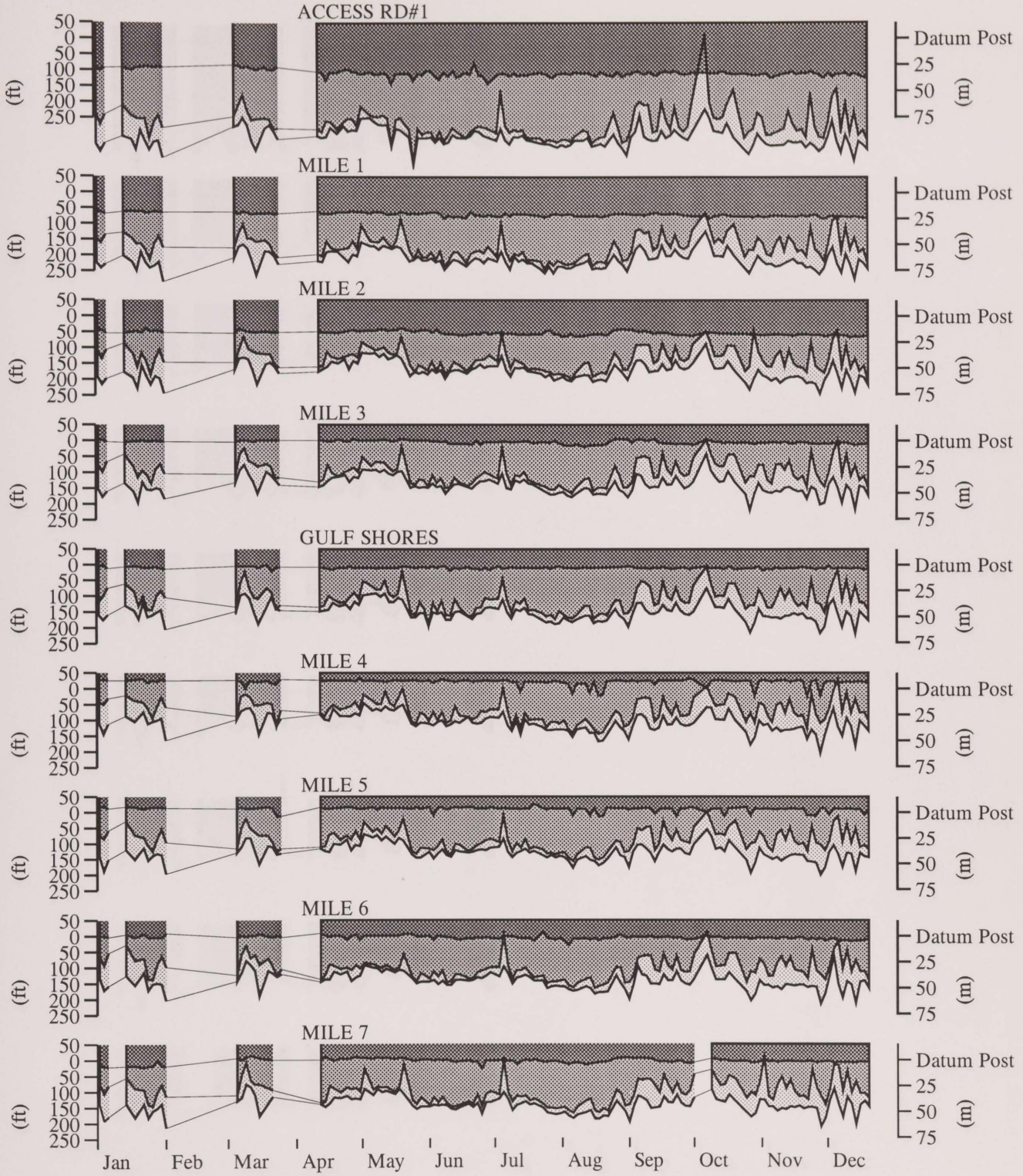



Figure 43. Location of dune line, high tide line and shoreline: 1999. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.


Figure 44. Location of dune line, high tide line and shoreline: 2000. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

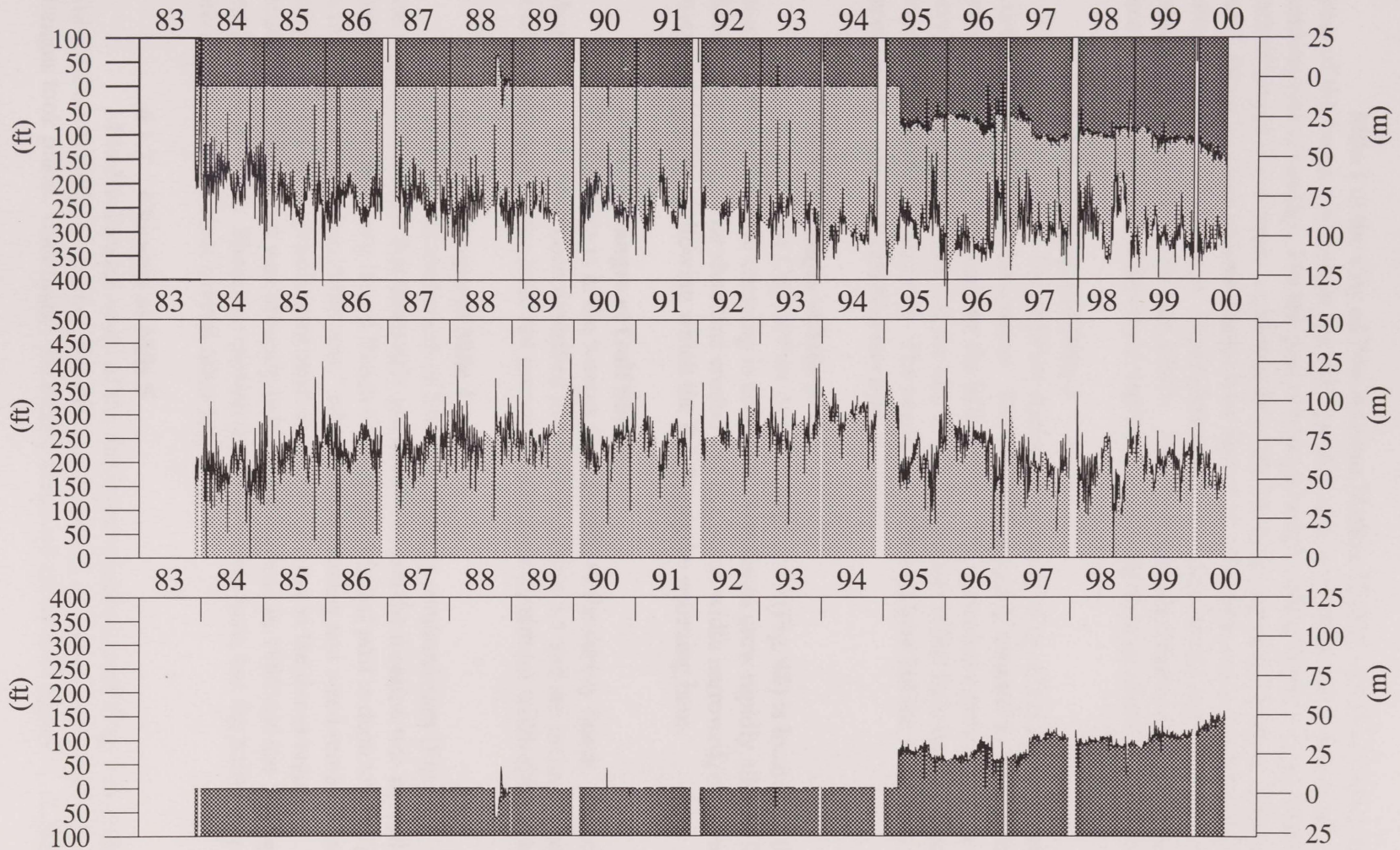



Figure 45. Seventeen years of changes to the beach and dunes at Gulf Access Road #1: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1995 to 2000. The years are shown at the top of each panel.

### 6.1.2 Changes at Mile 1

Mile 1 at the City of Port Aransas Marker 35 (Fig. 46) is in one of the least disturbed areas of the beach. Although sporadic grading and weed removal is done here, there are no condominiums nearby. For the past two years beach visitors from a large recreational vehicle park (Pioneer) have made a pathway through the dunes for beach access. There is no walkway here. Dune location measurements here and at all other sites were started in the fall of 1988, following Hurricane Gilbert. Dune growth has been continuous here, with setbacks following the tropical storm events of the late 1990's. The shoreline has remained quite stable throughout the measurement period, but the beach has been narrowing here as elsewhere due to dune accretion.

### 6.1.3 Changes at Mile 2

Mile 2 at the City of Port Aransas Marker 45 (Fig. 47) is located just south of El Cortez and Casadel condominiums. The beach is regularly cleaned in front of the condominiums and material put in the dunes by the Mile 2 site. The dunes have grown and the beach narrowed here, but the tropical storms of the late 90's had a greater effect here than at other locations and dune growth has been arrested. The beach has narrowed here but the trend may be lessening in recent years. Shoreline erosion has been minimal.

### 6.1.4 Changes at Mile 3

Mile 3 at the City of Port Aransas Marker 57 (Fig. 48) is located in the free parking area of the beach, where camping is common. The dunes grew rapidly after Gilbert but growth slowed after 1992. The shoreline eroded and the beach width narrowed, especially prior to Josephine in 1996, following which the beach may be widening here.

### 6.1.5 Changes at Gulf Shores

Gulf Shores is in the Nueces County area of the survey beach. The changes at Gulf Shores (Fig. 49) have been described in detail in section 5.1 and are included here for comparison. Note that the dunes here have not grown back to their maximum width since Josephine in 1996.

### 6.1.6 Changes at Mile 4

Mile 4 is located south of Mustang Towers condominium (Fig. 50). The datum post was a speed limit sign that ultimately got destroyed and the location was moved slightly south to the walkway of Mustang Island Beach Club. (The original post is depicted in Figure 66.) This is in the center of "condominium row," where beach grading and weed removal are done almost daily and piles of unconsolidated sand and debris are put in the dunes regularly. Dune growth was steady after Gilbert but was abruptly halted by Josephine in 1996 and the damage done by Charley and Frances in 1998. Shoreline erosion has been steady here, but the narrowing of the beach has been arrested, as it has at several other locations.

### 6.1.7 Changes at Mile 5

Mile 5 is located south of the Sandpiper condominium (Fig. 51). Originally it was at Nueces County Mile 12 marker, but this got destroyed or moved as various municipal jurisdiction changes took place. Eventually, the county removed all its mile markers. A dramatic

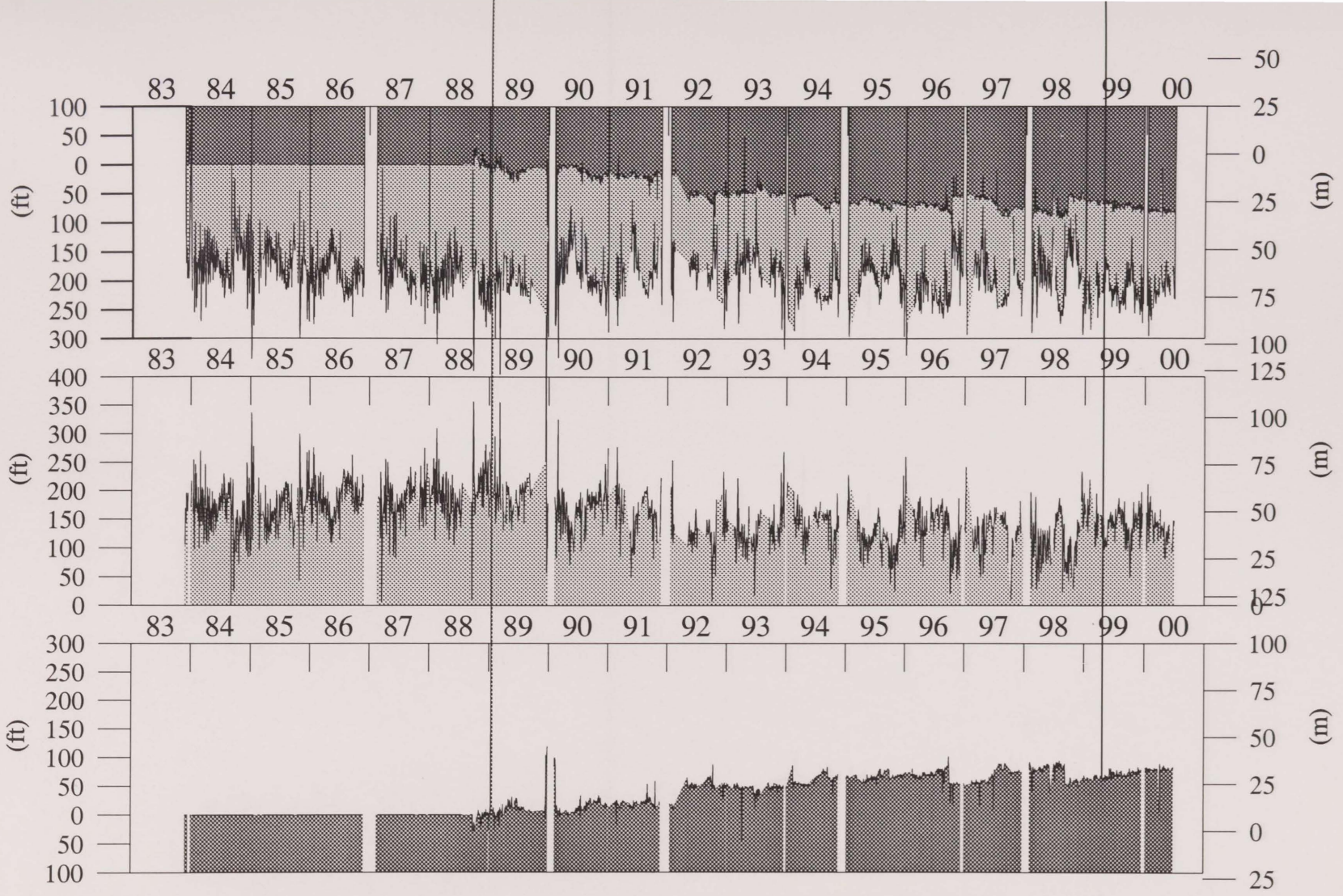



Figure 46. Seventeen years of changes to the beach and dunes at Mile 1: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

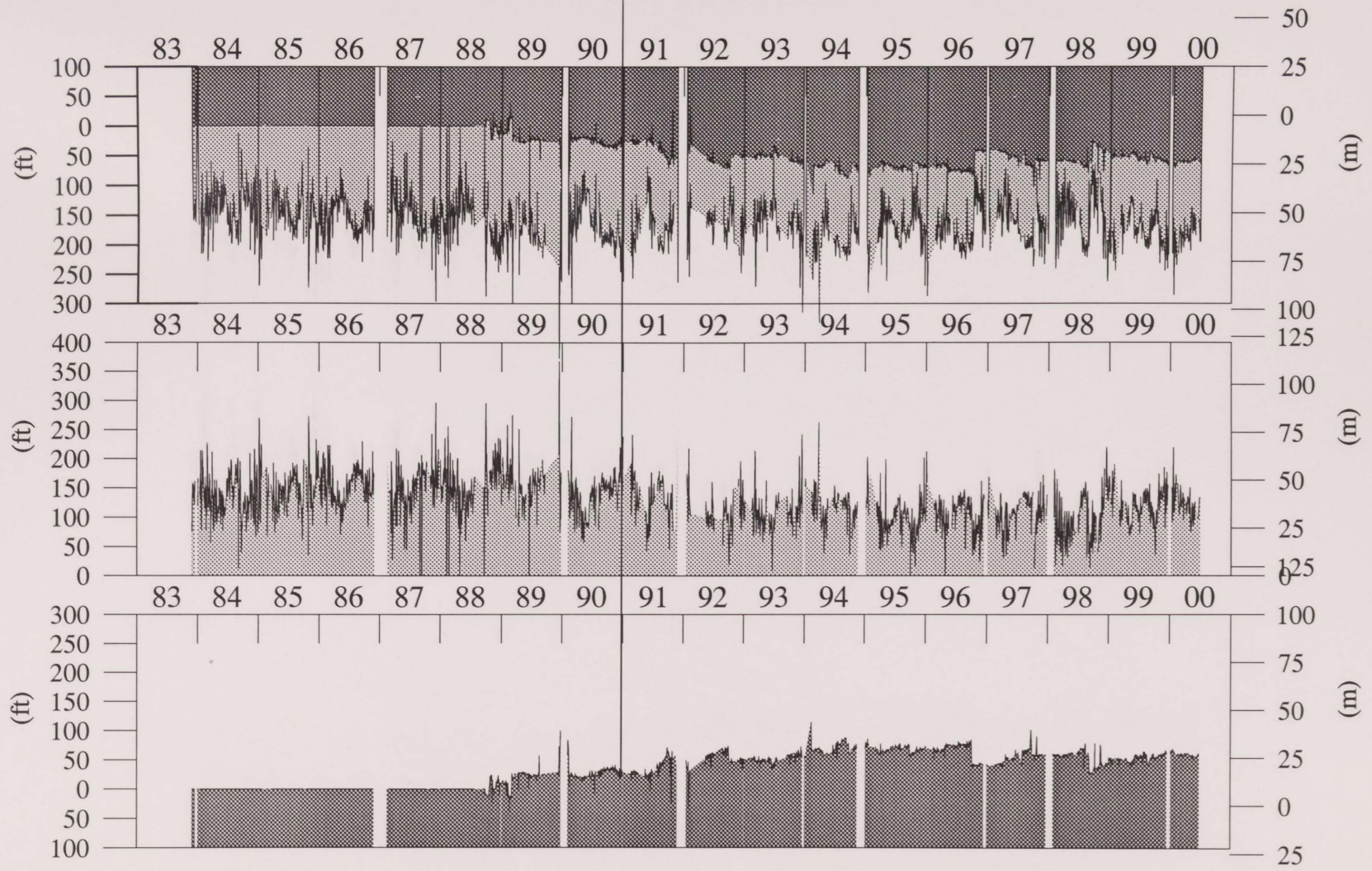



Figure 47. Seventeen years of changes to the beach and dunes at Mile 2: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

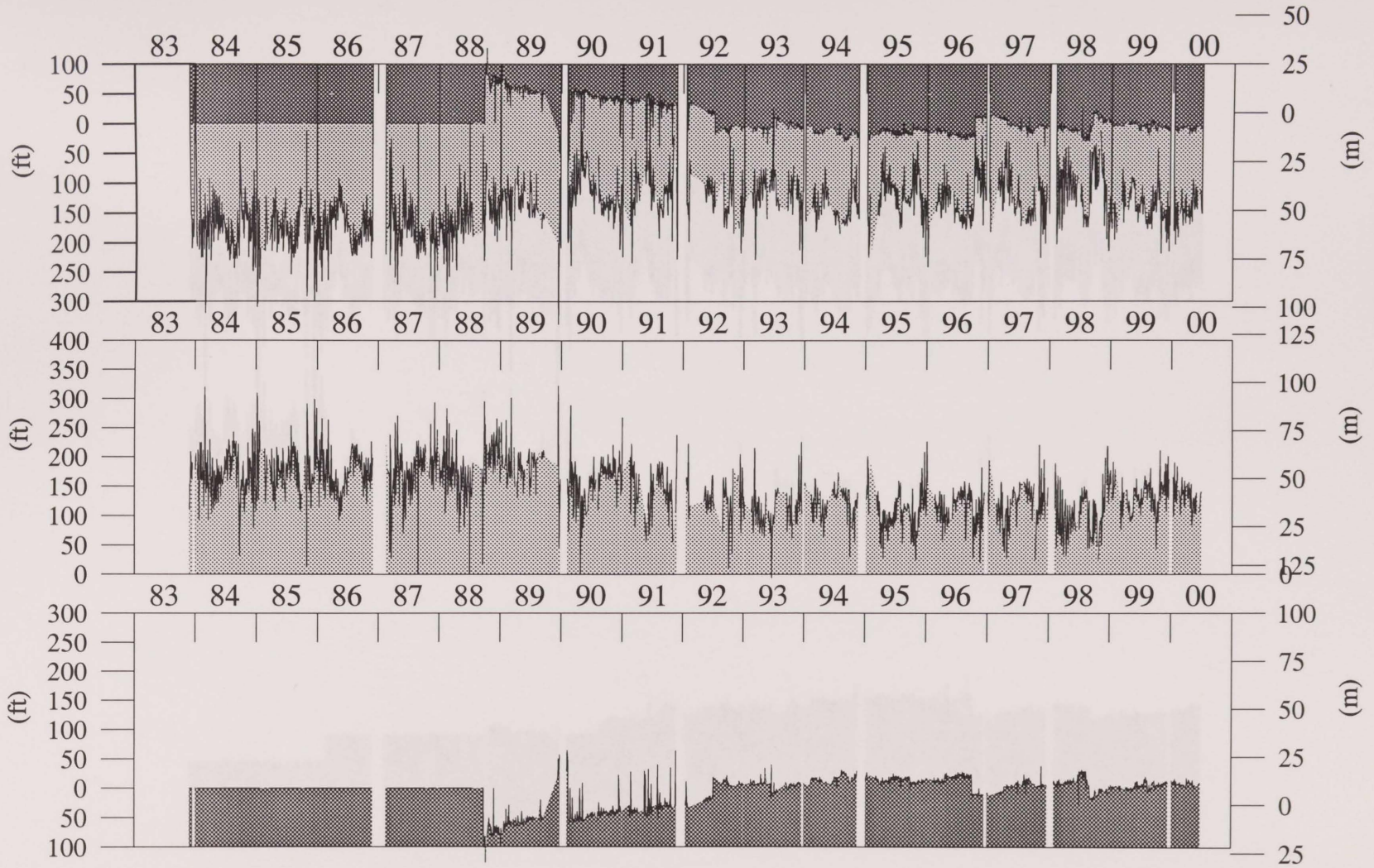



Figure 48. Seventeen years of changes to the beach and dunes at Mile 3: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

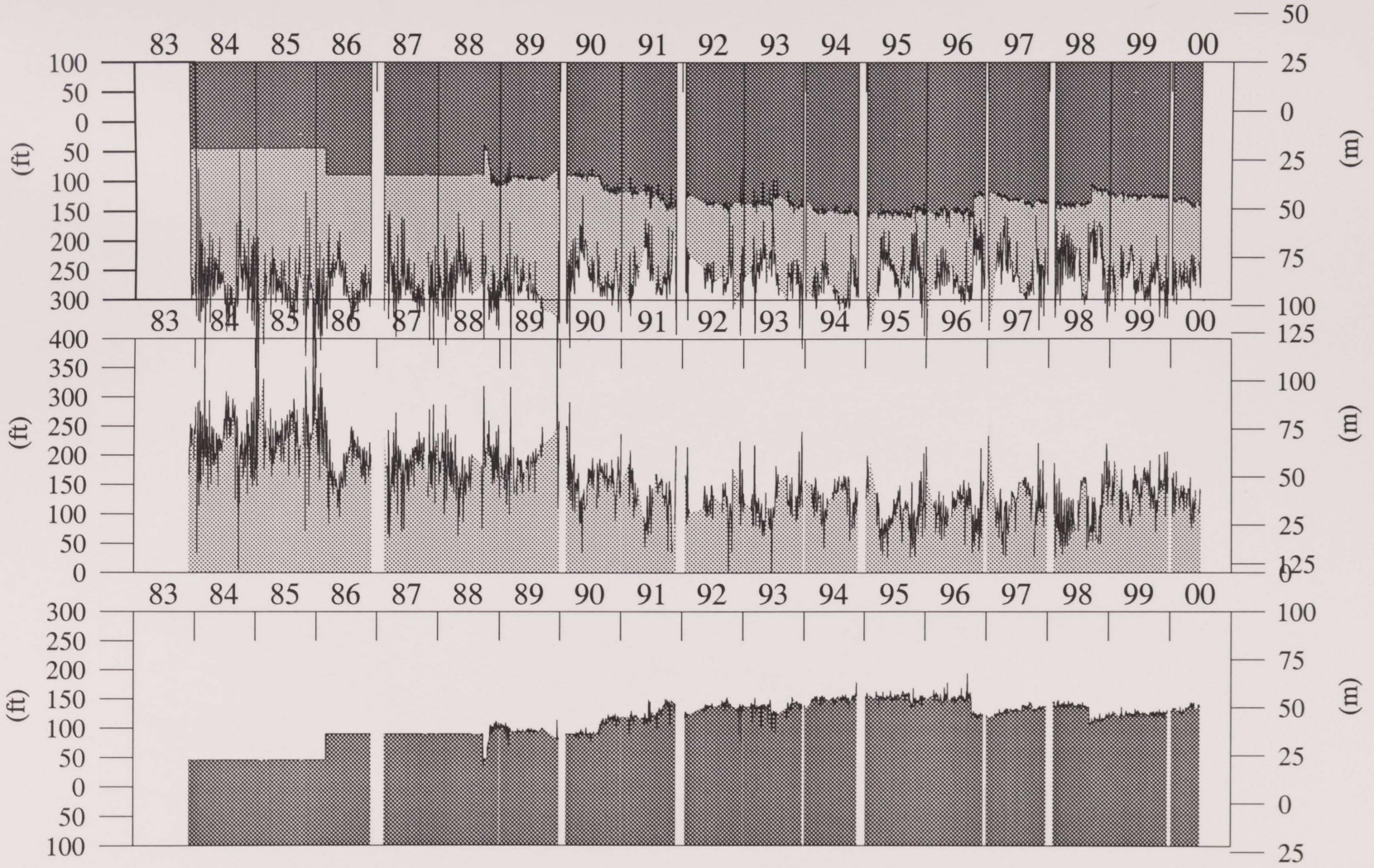



Figure 49. Seventeen years of changes to the beach and dunes at Gulf Shores: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

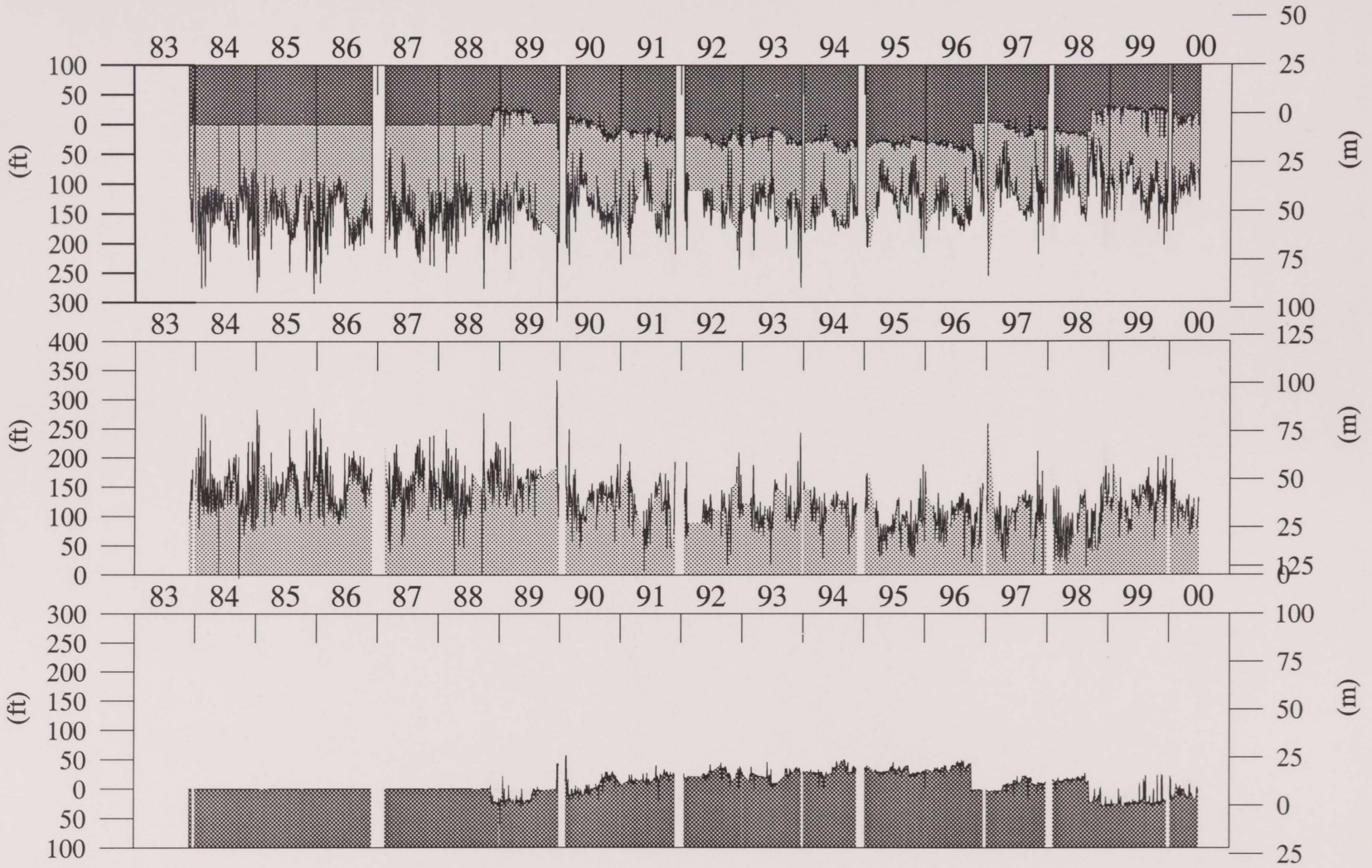



Figure 50. Seventeen years of changes to the beach and dunes at Mile 4: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

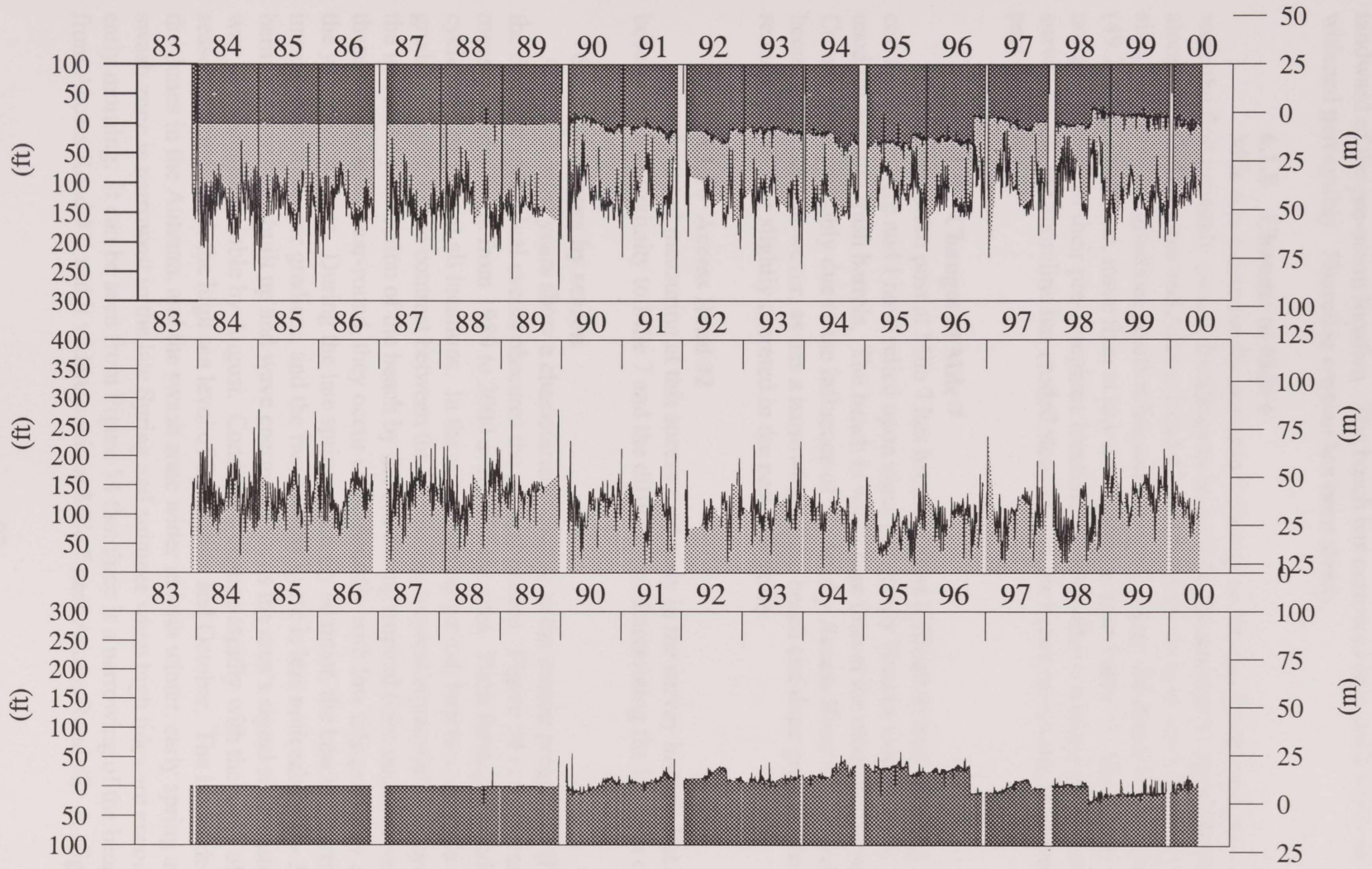



Figure 51. Seventeen years of changes to the beach and dunes at Mile 5: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

change to the dunes occurred here with the passage of Josephine and the dunes are now well landward of the pre-storm location. The beach has narrowed here until 1995, since when it has widened perceptibly. Shoreline erosion has been steady.

### 6.1.8 Changes at Mile 6

Mile 6 is located at the northern walkway of the two Private Houses (Fig. 52). These were the first privately owned dwellings to be built on the seafront in the study transect. This site, along with Gulf Shores and Access Road #1, has been the most consistent in its location of all the sites (i.e., their longitudinal position has not changed). Here the dunes were eroded back 15 m (49.2 ft) by Josephine, more than at any other location (see Table 7). Since then the dunes have not grown back to their pre-Josephine location. As with other locations on the southern part of the survey beach, the shoreline has eroded steadily, but the beach narrowed, then grew wider in the past few years.

### 6.1.9 Changes at Mile 7

The datum post at Mile 7 has been the most difficult to maintain (Fig. 53). There is no condominium here and I have relied upon signs (originally Nueces County Mile 10) and posts used for holding trash barrels. The beach is wider here than at the other locations in the Nueces County area, probably due to the influence of the nearby Access Road #2. Shoreline erosion has been steady here, however, as has a narrowing of the beach and dune growth (the latter two have remained stable or slightly accreted in the past two years.

### 6.1.10 Access Road #2

I started measuring at this access road early in the survey history, but abandoned this because of its proximity to Mile 7 and the difficulty of determining the location of the dunes.

## 6.2 Changes by season

Although most years show a characteristic change as the season progresses (Figures 45-53), the detail of individual events obscures the general pattern. Figure 54 is the mean of all measurements made from 1989 to 2000 at each of the sites. Both fortnightly and long-term tidal cycles can be seen at all locations. In the winter/spring period, beaches are wide and the beach gradient slight, hence contrast between the alternating tropical/equatorial tidal cycles is seen by the increased penetration of the beach by the sea during tropical tides and vice-versa. Although these cycles occur year-round, they occur coincidentally with low tide primarily in the first part of the year near sunrise. During the late spring and early summer, the beach is narrower, the sea impinges on a steeper gradient, and the two-weekly cycle is less noticeable. By July, a summer berm has normally built up and wave energy is less as the area's signal southeasterly wind give way to light and variable by August. Conditions change rapidly with the onset of the storm season, coupled with the high sea level of September and October. The high tide line is closer to the dunes in the Autumn, and the swash zone wider in both winter, early spring and fall. The swash zone is narrowest in the late Spring and summer when high tides are encountered in the early morning. It can be seen from Figure 54 that there is a narrowing of the beach going south from Access Road #1, and it widens again at Mile 7 near Access Road #2. A slight increase in

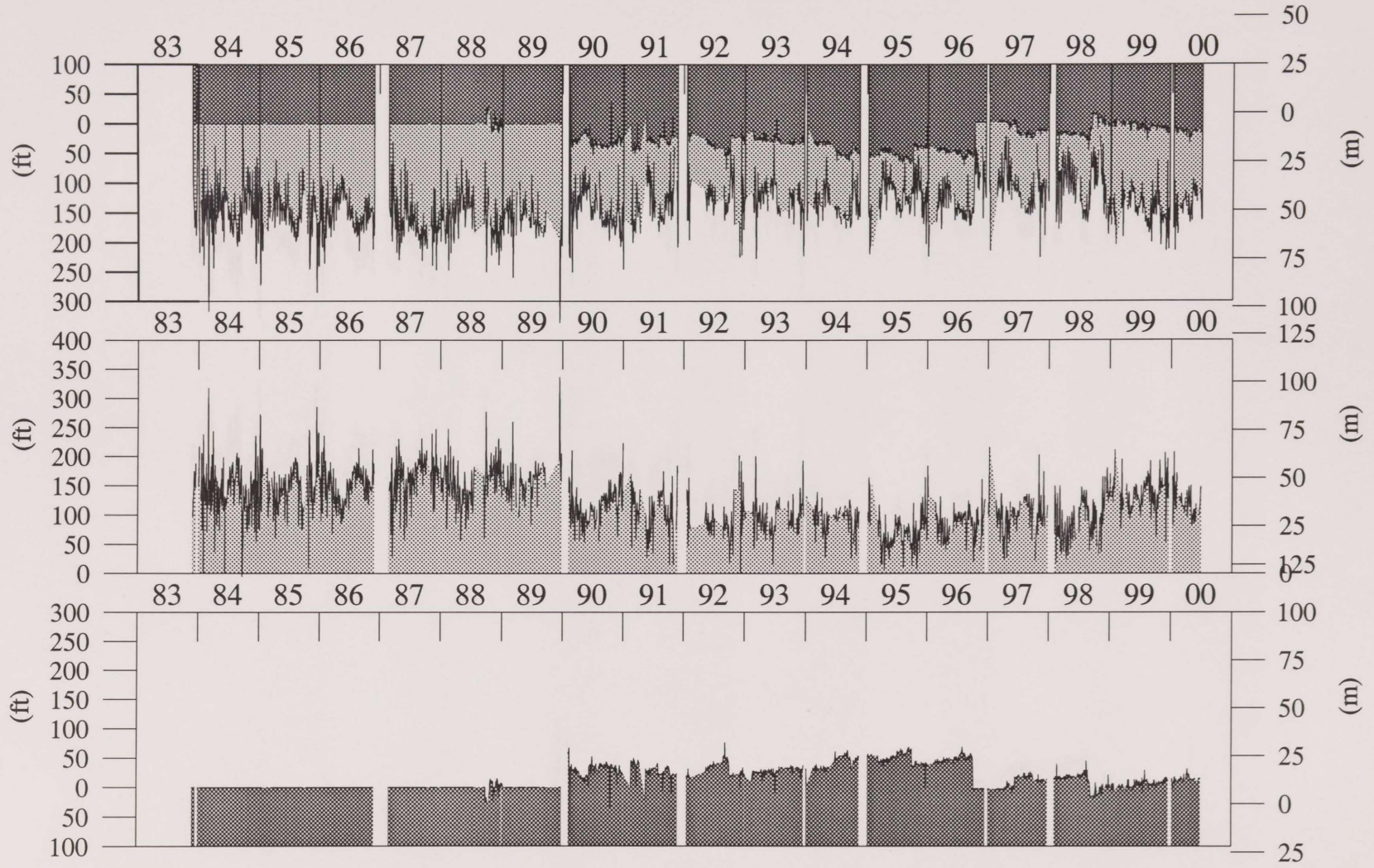



Figure 52. Seventeen years of changes to the beach and dunes at Mile 6: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

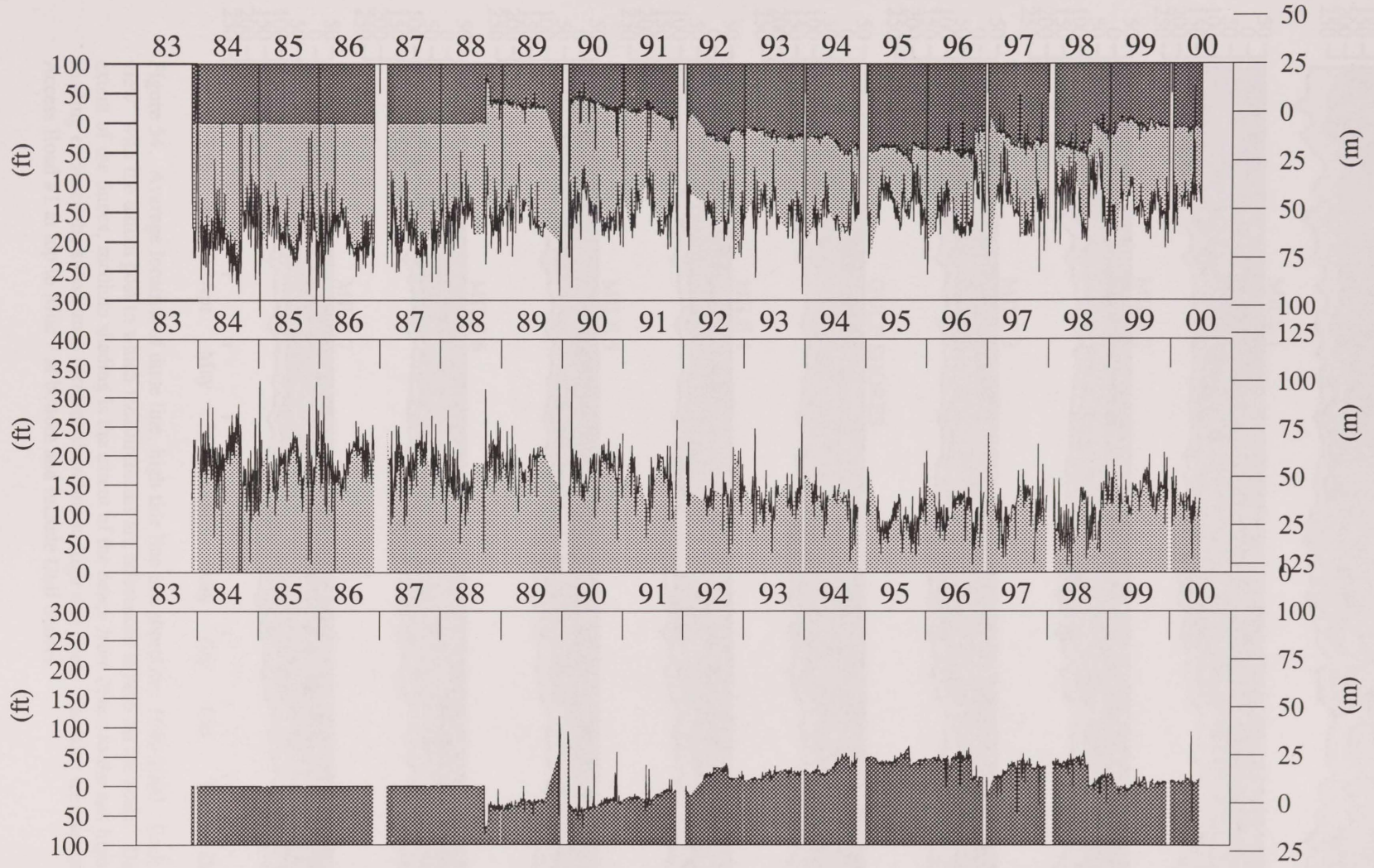



Figure 53. Seventeen years of changes to the beach and dunes at Mile 7: 1983-2000. Top panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Dark shading shows the extent of the dunes, lighter shading is the extent of the beach from dunes to the shoreline. Middle panel is the beach width relative to the dunes (zero on scale). Bottom panel shows changes in dune line relative to the datum post (zero on scale). Measurements to the dune line were only made at this location from 1988 to 2000. The years are shown at the top of each panel.

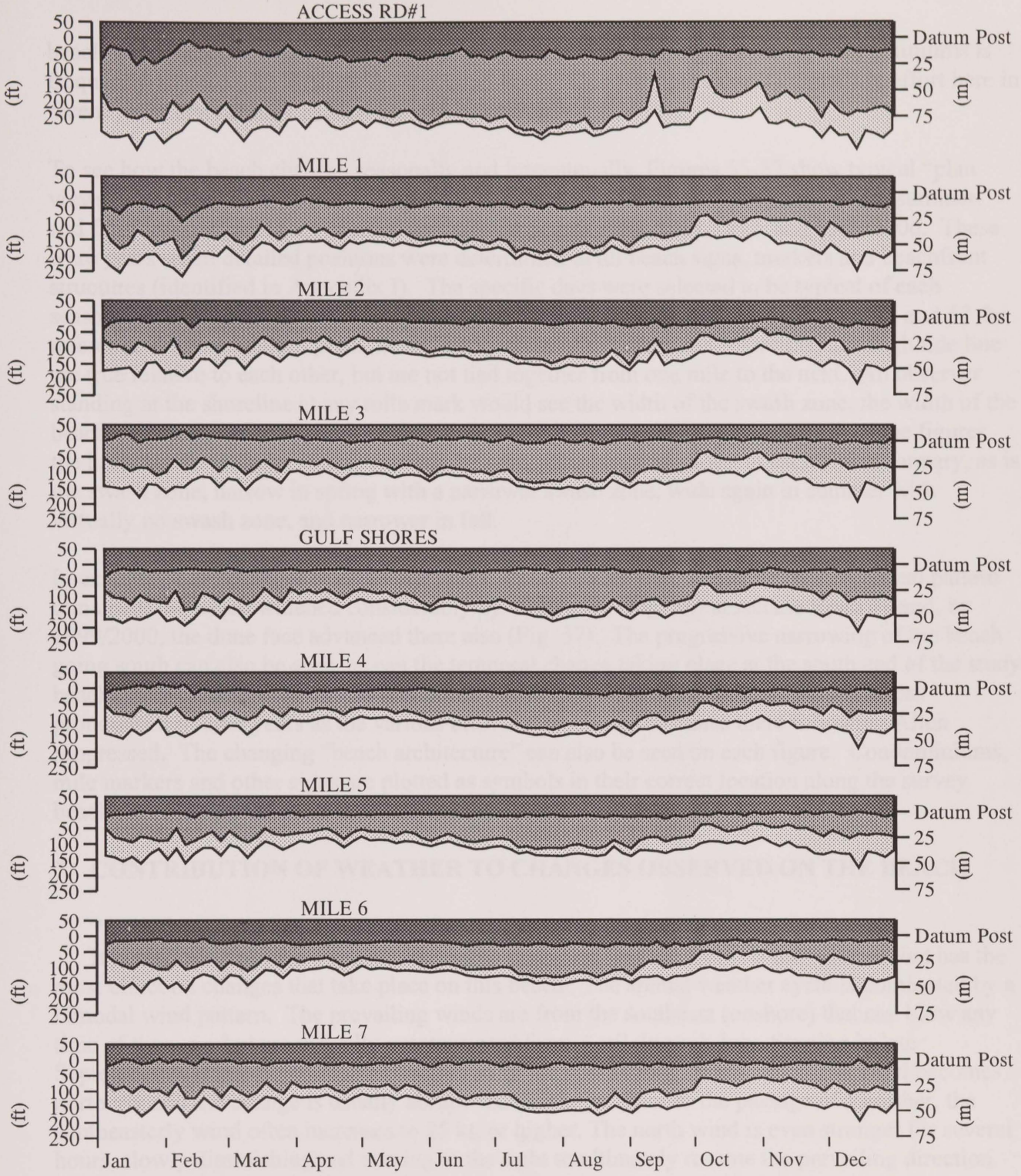



Figure 54. Average location of dune line, high tide line and shoreline: 1989-2000. Each panel is a "plan view" with the datum post to which measurements are referenced at zero on the scale. Darkest shading shows the extent of the dunes, medium shading is the extent of the beach from dunes to the last high tide line, lightest shading encloses the swash zone (present shoreline to high tide line). The nine measurement sites go from Access Road #1 at top to Mile 7 at bottom and include Gulf Shores.

beach width is found around Mile 3 and Gulf Shores. The region south of the condominiums is frequently narrow with difficult driving conditions. This prompts a constant grading effort here in recent years that actually exacerbates the condition.

To see how the beach changes seasonally and interannually, Figures 55-57 show typical "plan views" along the survey transect made during selected observations in winter, spring, summer, and fall for three years (not necessarily calendar years) 1984, 1991/1992, and 1999/2000. These were years when detailed positions were determined of all beach signs, markers and beachfront structures (identified in Appendix I). The specific days were selected to be typical of each seasonal tidal regime. The reference in Figure 55 is the dune line, while in Figures 56 and 57 the reference is a fixed datum point, hence the location of the dune line, shoreline, and high tide line are true relative to each other, but are not tied together from one mile to the next. An observer standing at the shoreline at any mile mark would see the width of the swash zone, the width of the beach and the distance to the dune line as true relative to the datum post. In each of the figures the basic beach changes with season can be seen. The beach is widest at each site in January, as is the swash zone, narrow in spring with a narrower swash zone, wide again in summer with virtually no swash zone, and narrower in fall.

In examining the changes over several years, it can be seen that, while the basic seasonal pattern remained, the beach widened considerably by 1991/1992 (Fig. 56) at Access Road #1 and, by 1999/2000, the dune face advanced there also (Fig. 57). The progressive narrowing of the beach going south can also be seen, as can the temporal change taking place at the south end of the study beach: the widening there is less pronounced with time. The bulge at Gulf Shores is less pronounced in later years as the various efforts at restoring the dunes there following Allen progressed. The changing "beach architecture" can also be seen on each figure. Condominiums, mile markers and other signs are plotted as symbols in their correct location along the survey beach (but their positioning in relation to the shoreline is arbitrary).

## 7. CONTRIBUTION OF WEATHER TO CHANGES OBSERVED ON THE BEACH

### 7.1 Effects of the annual weather cycle

It is obvious from the data and discussion presented this far, that it is the weather that has the most effect on changes that take place on this beach. The annual weather cycle is dominated by a bimodal wind pattern. The prevailing winds are from the southeast (onshore) that can blow any time of the year, but are virtually uninterrupted from April through July. Starting in late September cold fronts (northers) sweep in from the north every several days. The wind becomes northerly and the change is usually abrupt and dramatic. Prior to the passage of a norther, the southeasterly wind often increases to 25 kt, or higher. The north wind is even stronger for several hours, slowly diminishing and veering to the right to ultimately resume the prevailing direction. A sharp temperature drop occurs with each cold front and the normally high humidity drops as well. The effect on the beach is noticeable. With the southeasterly wind, sand blows from the beach into the dunes and onto the back-beach area. Strong wave action erodes the fore-beach and raises the sea level above the normal astronomical tide level. The north wind immediately

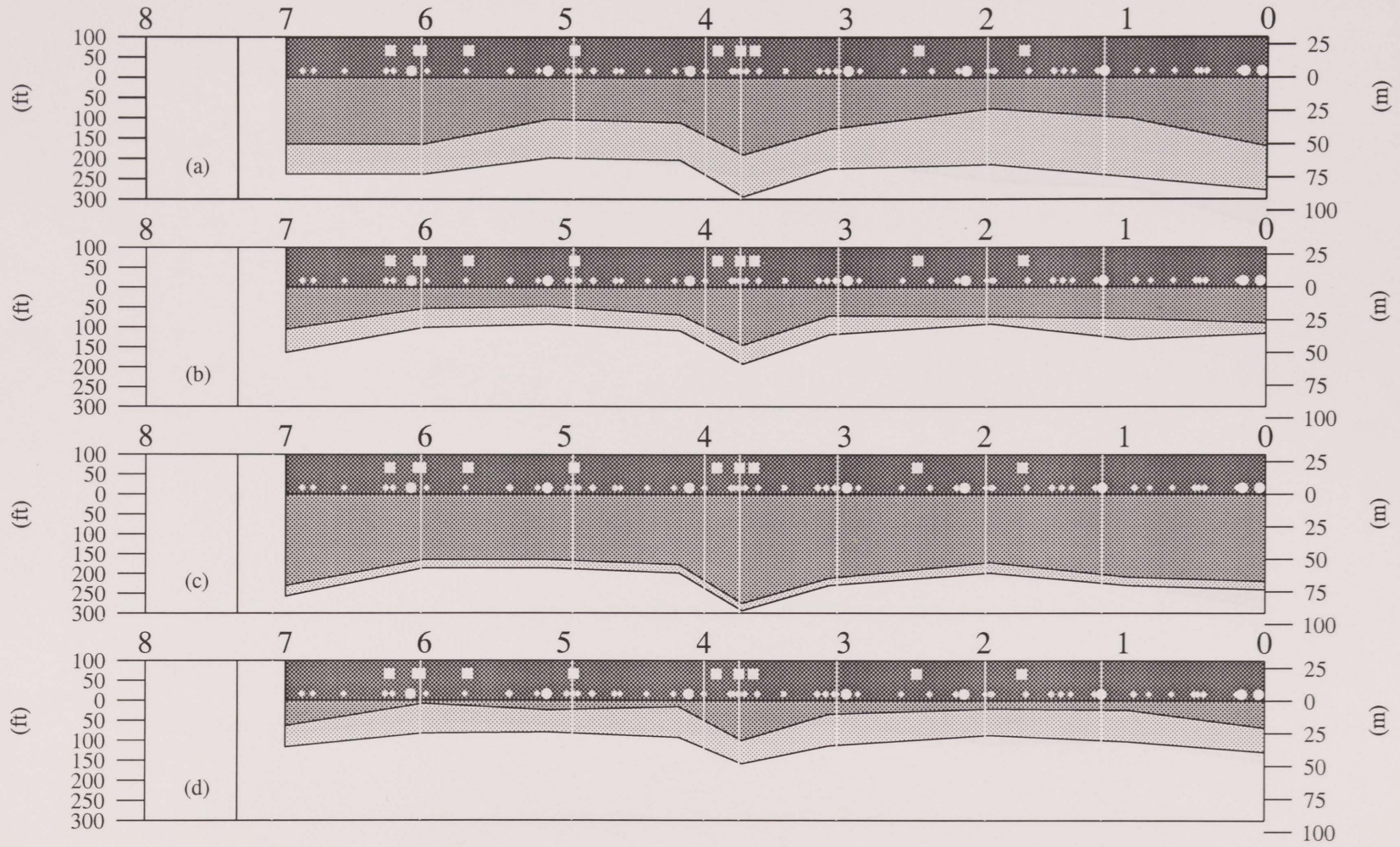



Figure 55. Seasonal changes in beach and swash zone widths relative to the dunes: 1984. Each panel is a "plan view" of the beach on a typical day in winter, spring, summer and fall. On each panel, Access Road #1 is on the right and mile measuring sites are labeled along the top. Dark shading represents the dunes (at zero on the scale), medium shading is beach width to the last high tide line and lightest shading bounds the swash zone (shoreline to high tide line). Square symbols show location of condominiums, large circles are beach distance marker posts, small triangles are beach signs (as of Jan 7 1983). Distance of these features realtive to Access Road #1 is correct, distance relative to the dune line is arbitrary. Measurements were made on (a) Jan 29 1984, (b) April 30 1984, (c) July 20 1984 and (d) October 18 1984.

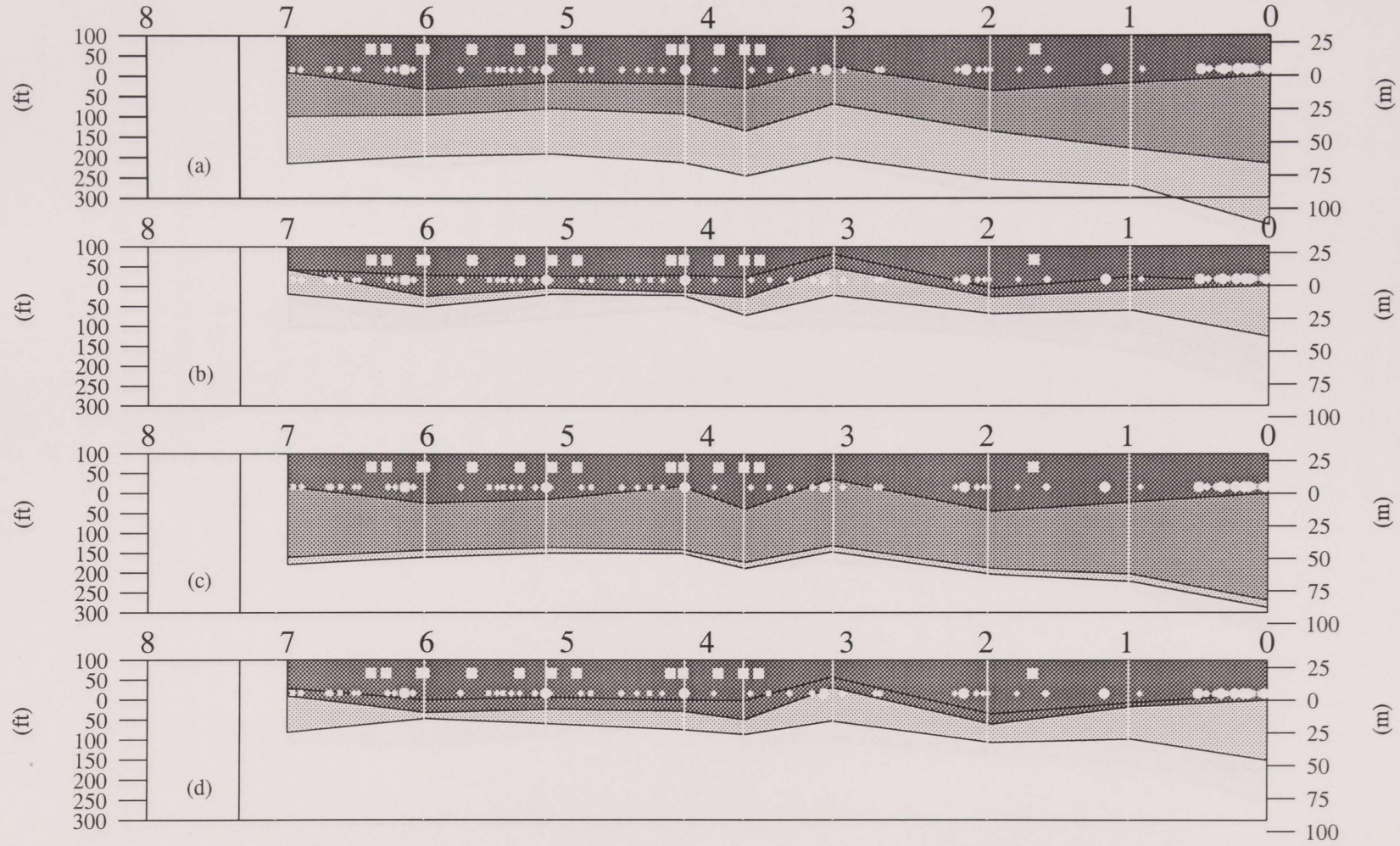



Figure 56. Seasonal changes in beach and swash zone widths relative to the dunes: 1991/1992. Each panel is a "plan view" of the beach on a typical day in winter, spring, summer and fall. On each panel, Access Road #1 is on the right and mile measuring sites are labeled along the top. Dark shading represents the dunes (at zero on the scale), medium shading is beach width to the last high tide line and lightest shading bounds the swash zone (shoreline to high tide line). Square symbols show location of condominiums, large circles are beach distance marker posts, small triangles are beach signs (as of June 6 1992). Distance of these features realtive to Access Road #1 is correct, distance relative to the dune line is arbitrary. Measurements were made on (a) Jan 31 1992, (b) May 23 1991, (c) Aug 22 1991 and (d) Oct 7 1991.

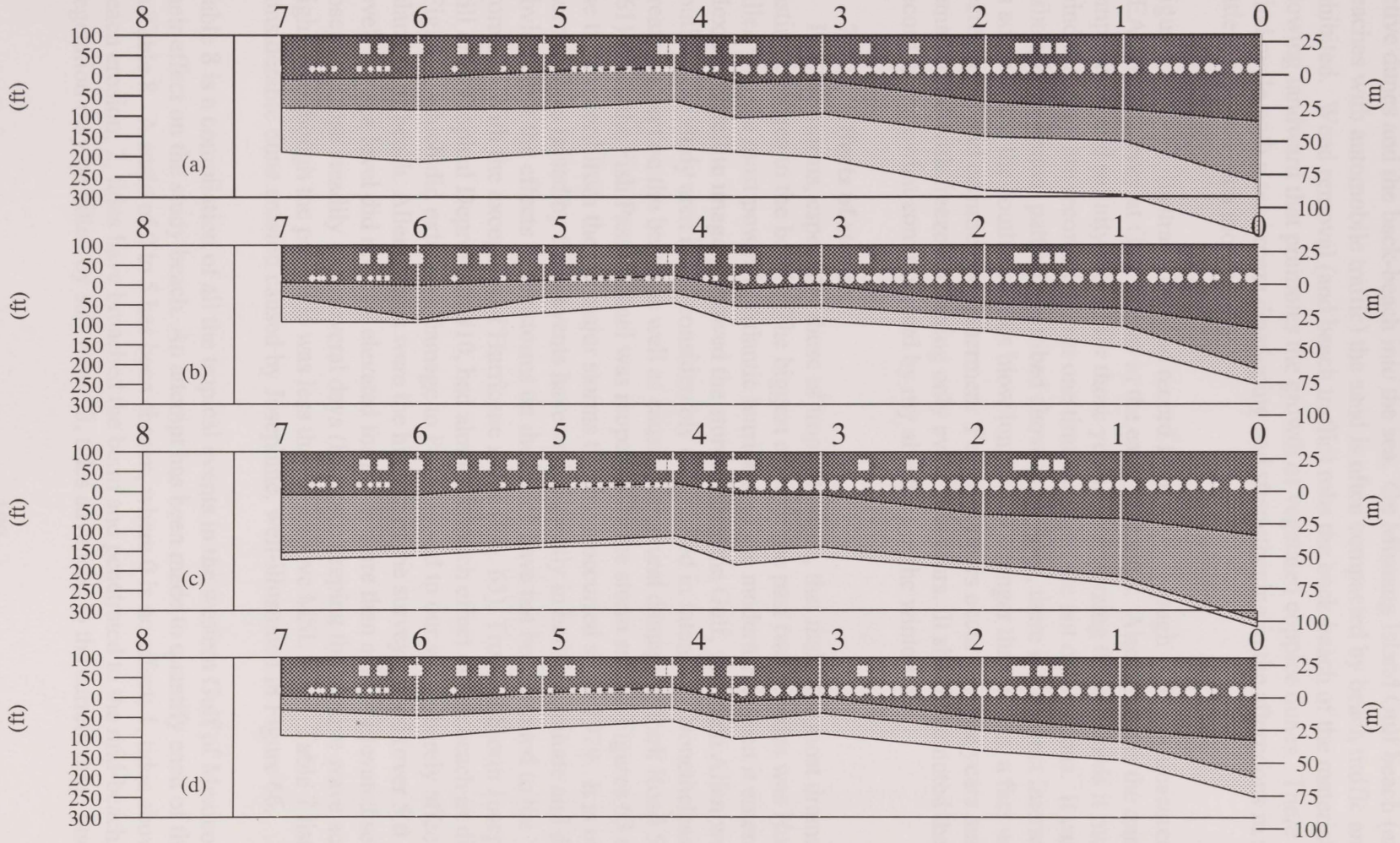



Figure 57. Seasonal changes in beach and swash zone widths relative to the dunes: 1999/2000. Each panel is a "plan view" of the beach on a typical day in winter, spring, summer and fall. On each panel, Access Road #1 is on the right and mile measuring sites are labeled along the top. Dark shading represents the dunes (at zero on the scale), medium shading is beach width to the last high tide line and lightest shading bounds the swash zone (shoreline to high tide line). Square symbols show location of condominiums, large circles are beach distance marker posts, small triangles are beach signs (as of August 19 2000). Distance of these features realtive to Access Road #1 is correct, distance relative to the dune line is arbritrary. Measurements were made on (a) Jan 20 2000, (b) May 1 1999, (c) Jul 30 1999 and (d) Oct 8 1999.

dampens the waves and lowers sea level at the shoreline. Sand now blows back seaward from active dunes and the back-beach into the sea. On Mustang Island Gulf beach (and other Texas beaches with automobile traffic) the sand is often compacted by beach traffic and sand transport is inhibited. Weed removal (and beach traffic) robs the back-beach of the material that can trap sand blowing landward that promotes the growth of vegetated coppice dunes. There is also a diurnal wind cycle with a sea breeze developing and strengthening in the afternoons in summer. This has little effect on beach morphology.

Figures 58 to 62 illustrate the wind record from 1979 through 1999, as measured during each BEACHobs survey at Gulf Shores in the early mornings. Also shown is the annual sea temperature and salinity record for those years. In analyzing these records it must be borne in mind that they are records taken at one time only and are not daily means. It can be seen that although the annual pattern described above is obvious, there is a distinct interannual variability. In some years, the southeasterlies blow longer and stronger than others, a fact well-known to local recreational and commercial fishermen. Fewer northers occur in some years and the winters remain mild with freezes occurring only every few years. It should be noted that the BEACHobs record is somewhat compromised by my absences in the wintertime.

### 7.2 Effects of storms

It is the storms, especially those of tropical origin, that make the most dramatic and longest-lasting changes to the beach. The biggest event of the past two decades was Hurricane Allen. Allen was the most powerful Atlantic hurricane of the modern era when it entered the Gulf of Mexico. Satellite imagery showed the storm filling the Gulf, yet when Allen went ashore to the south of the study area it had considerably diminished in intensity. Nonetheless, Allen had the greatest effect on the beach as well as causing structural damage to Park Road 53 (now Highway 361) when the Fish Pass channel was reopened by the storm surge. Figures 63 through 65 show the tidal record from the six major storms that have occurred since 1979. It is obvious that the storm surges raised by these events have varied greatly in both magnitude and duration. It is also obvious that the effects of the storms on the beach have not been limited to the "big name storms." With the exception of Hurricane Allen (Fig. 63), Tropical Storm Josephine, while it was still only Tropical Depression #10, had almost as much effect on the beach as did Allen. Brett (Fig. 65), which did extensive damage to Padre Island to our south, barely affected Mustang Island Gulf beach. Allen's tides were the highest of the survey period (over 5 ft above mean sea level) but sea level did not stay elevated for much more than a day. Elevated sea levels due to Josephine rose steadily over several days (Fig. 64), keeping the erosive wave action on the beach high, even though the peak tide was less than 3 ft above MSL tides. Table 7 lists the extent of the considerable dune erosion caused by Josephine, well-illustrated in Figure 66.

Table 8 is a compilation of all the tropical events in the western Gulf of Mexico since 1979 and their effect on the study beach. An attempt has been made to quantify each of the 62 storms listed in Table 8. A scale of 0 to 5 has been chosen, where 0 is no effect; 1, tides above the norm, no beach erosion; 2, tides have broached the berm and penetrated to the mid-beach, mid-beach vegetation may be killed by salt water; 3, tides advanced to the current dune line, eroding the

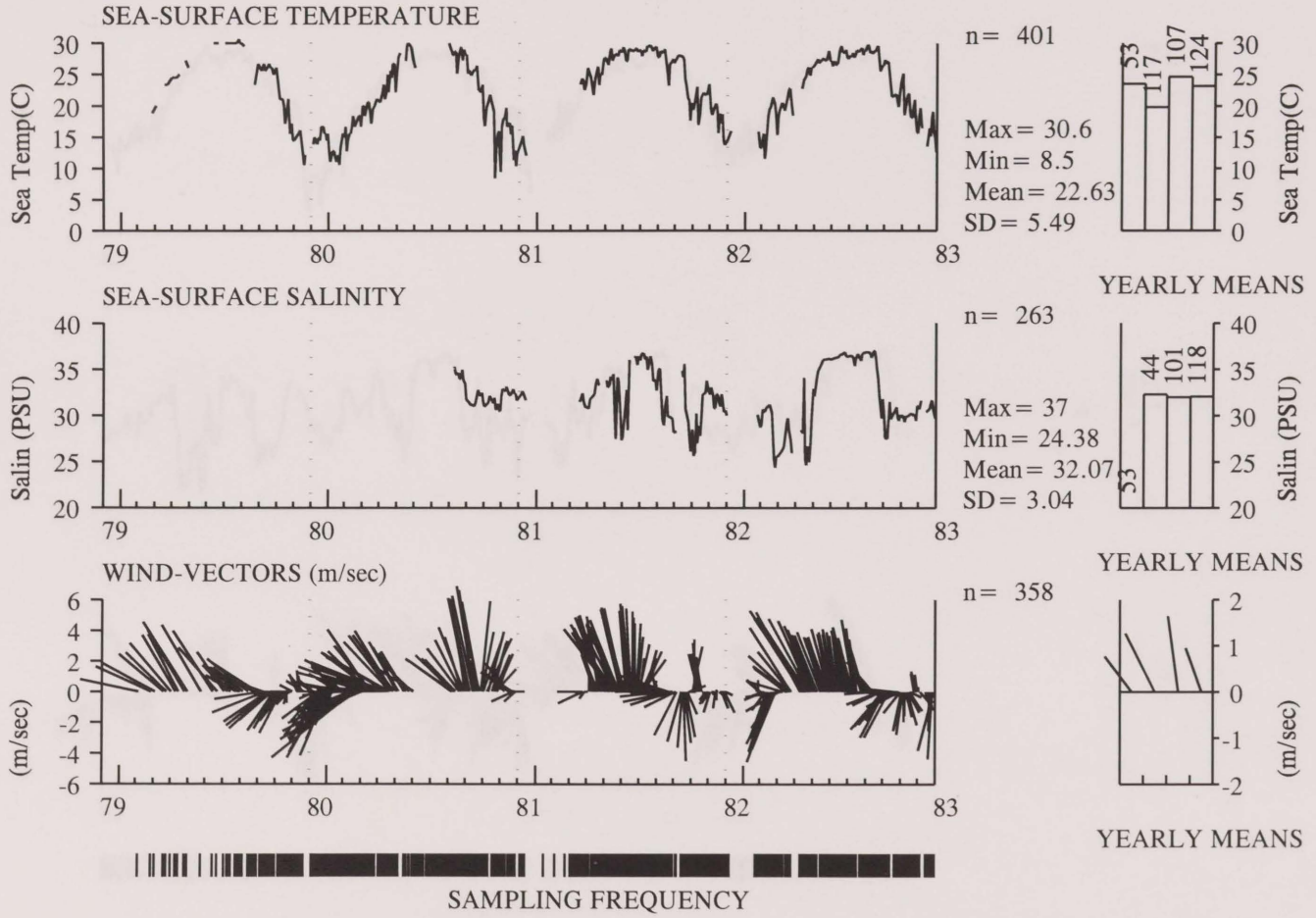



Figure 58. Wind and sea conditions at Gulf Shores; 1979-1983. Measurements taken on each BEACHobs survey after sunrise. Statistical data and yearly means shown to the righ of each panel. Wind vectors are in meters per second. Salinity is given in PSU (Practical Salinity Units). Salinity measurements were commenced in September 1980.

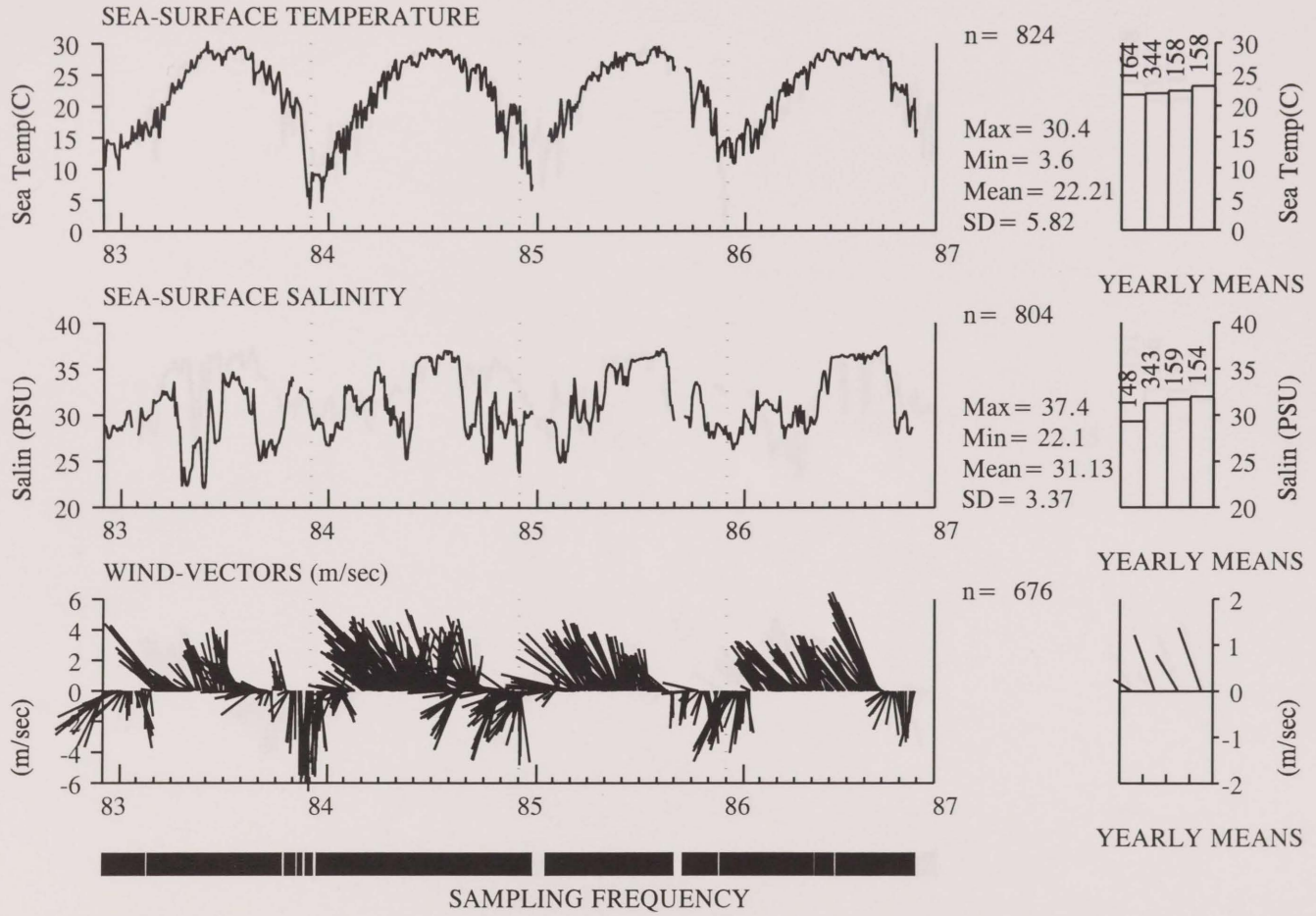



Figure 59. Wind and sea conditions at Gulf Shores; 1983-1987. Measurements taken on each BEACHobs survey after sunrise. Statistical data and yearly means shown to the righ of each panel. Wind vectors are in meters per second. Salinity is given in PSU (Practical Salinity Units).

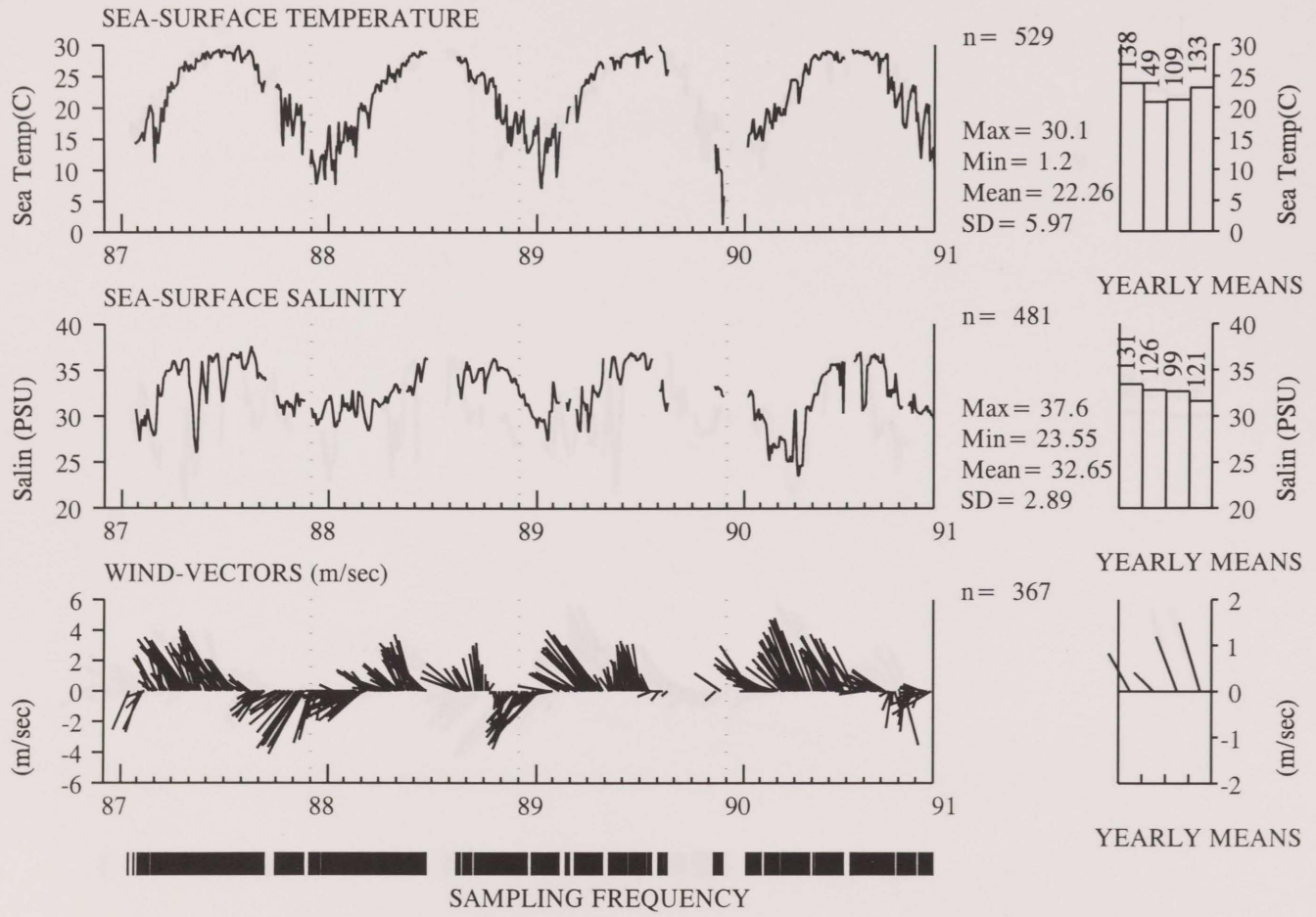



Figure 60. Wind and sea conditions at Gulf Shores; 1987-1991. Measurements taken on each BEACHobs survey after sunrise. Statistical data and yearly means shown to the righ of each panel. Wind vectors are in meters per second. Salinity is given in PSU (Practical Salinity Units).

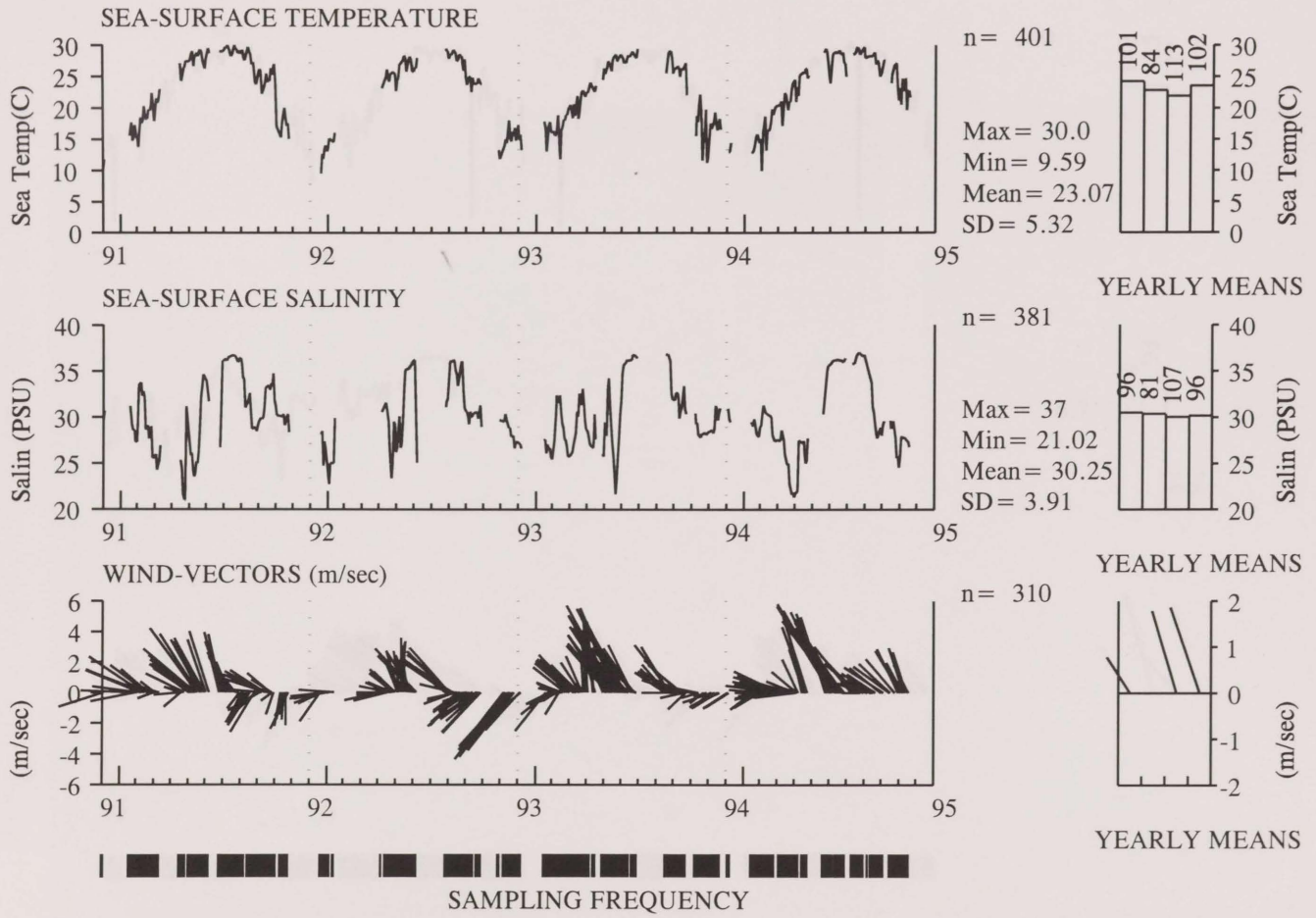



Figure 61. Wind and sea conditions at Gulf Shores; 1991-1995. Measurements taken on each BEACHobs survey after sunrise. Statistical data and yearly means shown to the righ of each panel. Wind vectors are in meters per second. Salinity is given in PSU (Practical Salinity Units).

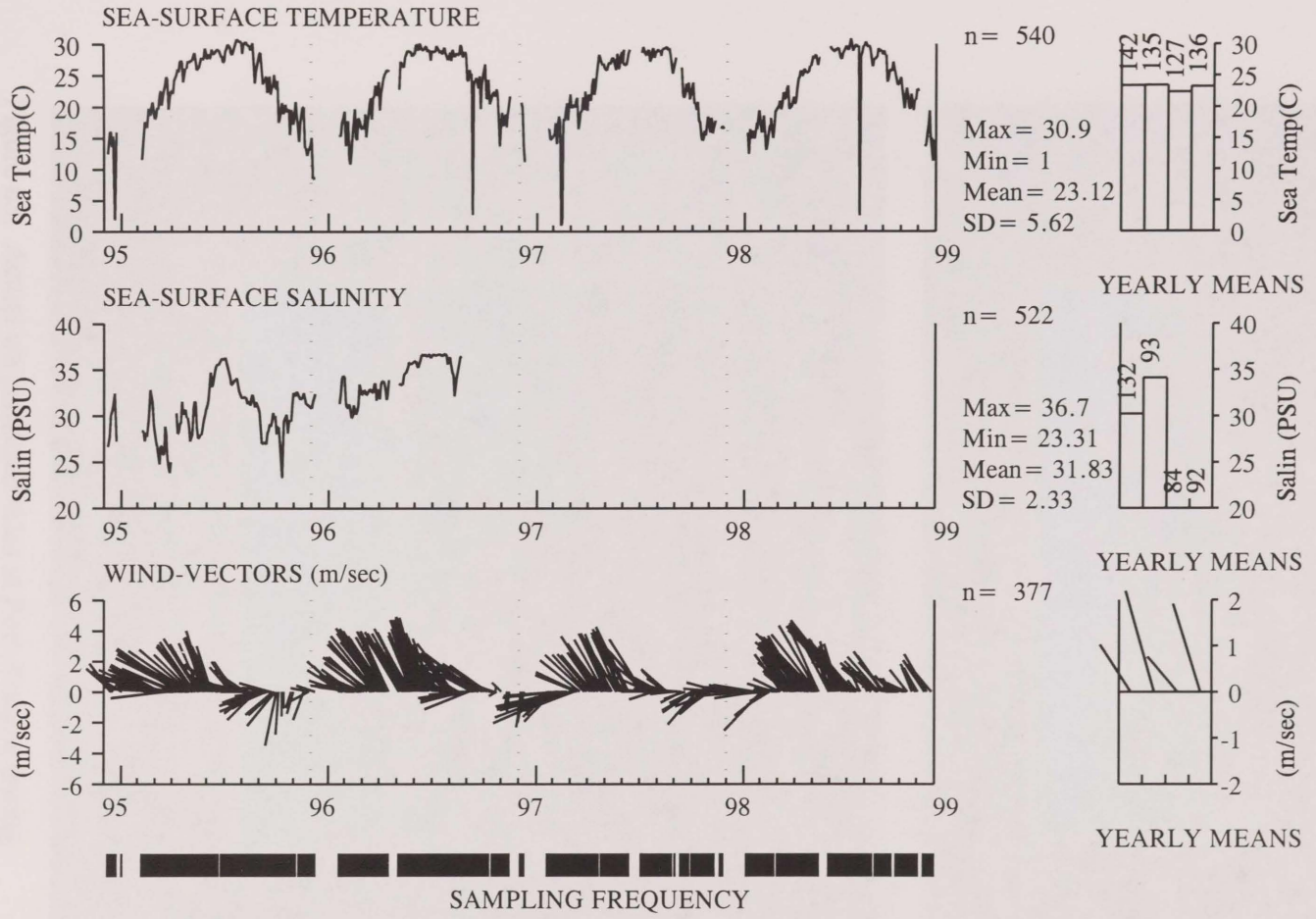
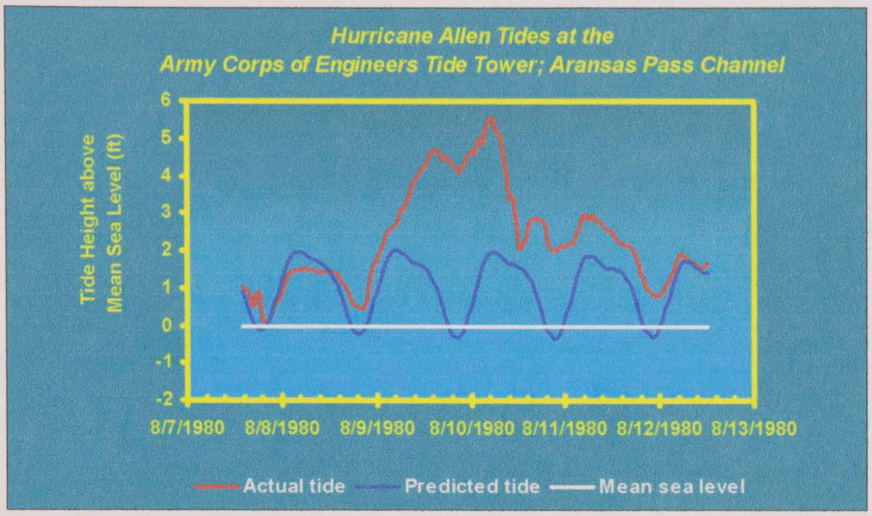



Figure 62. Wind and sea conditions at Gulf Shores; 1995-1999. Measurements taken on each BEACHobs survey after sunrise. Statistical data and yearly means shown to the righ of each panel. Wind vectors are in meters per second. Salinity is given in PSU (Practical Salinity Units). Salinity data after mid-1996 have not yet been reconciled.



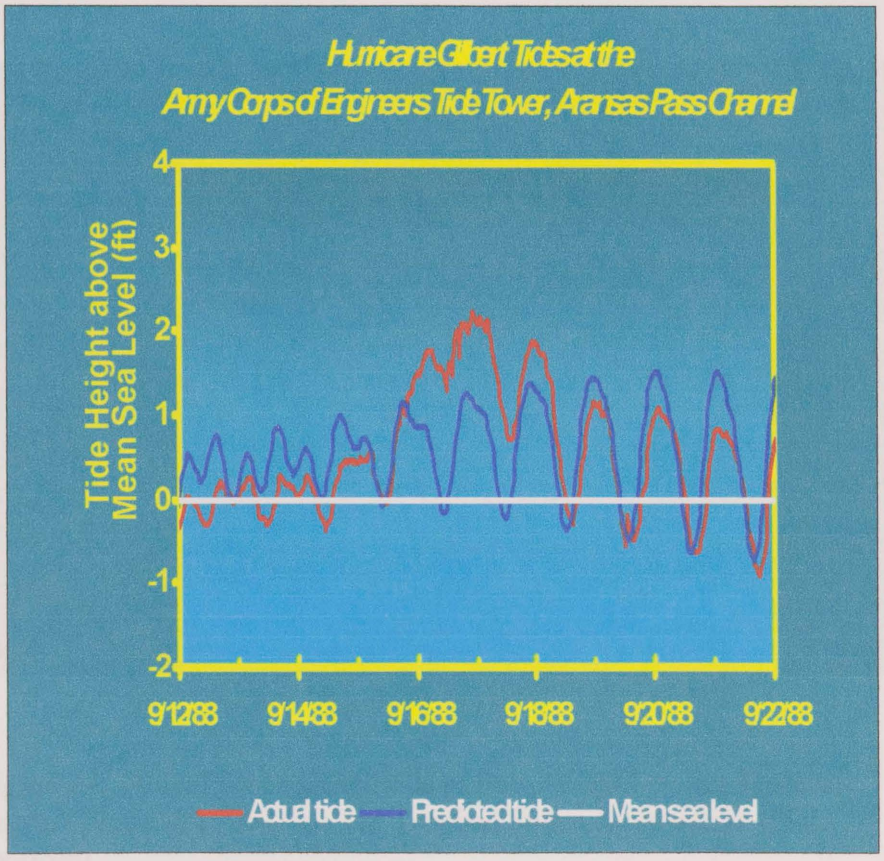




Figure 63. Actual v/s predicted tides at Port Aransas during Hurricane Allen in 1980 (top) and Hurricane Gilbert in 1988 (bottom).

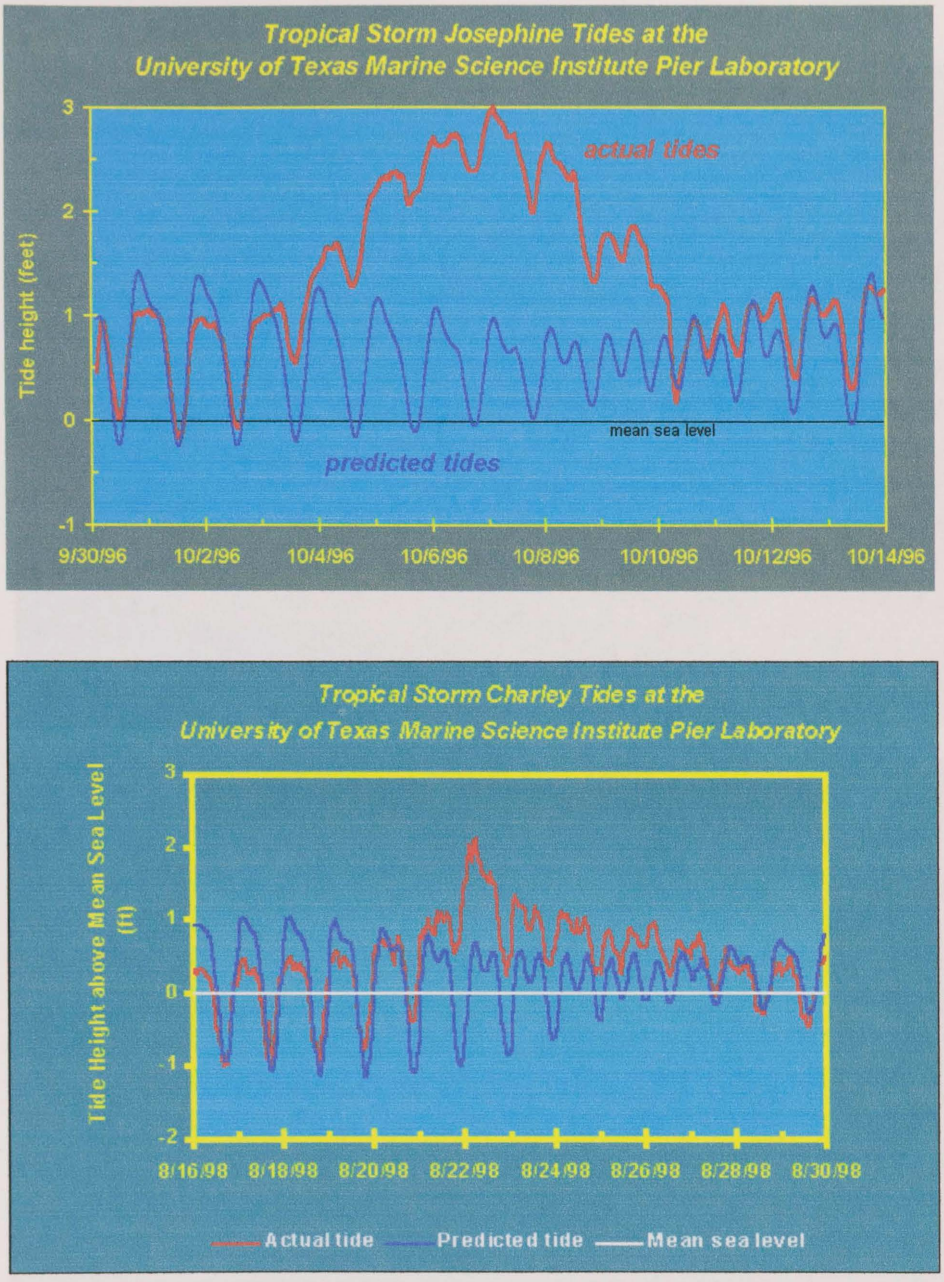
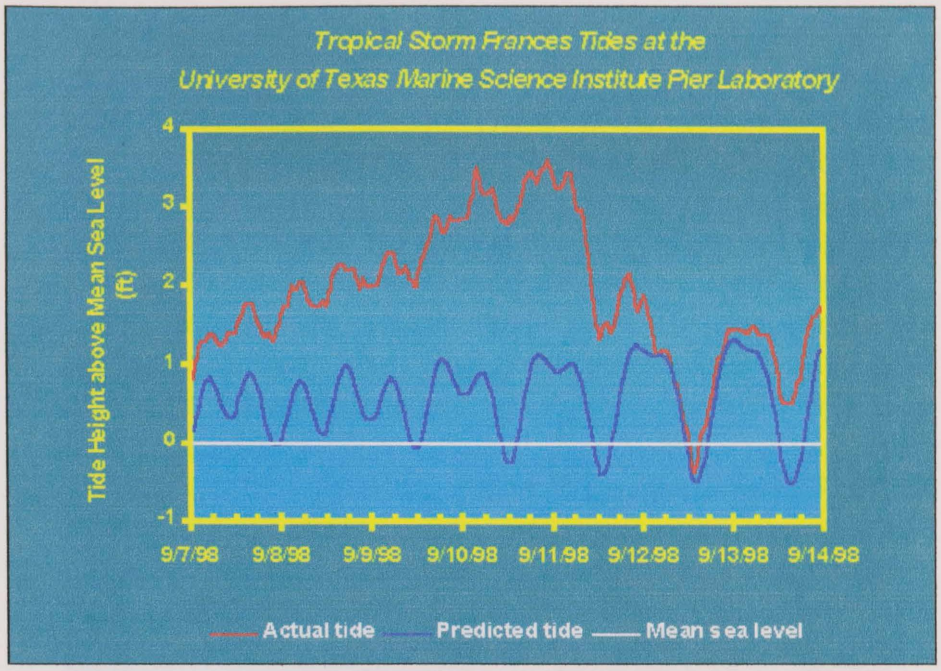



Figure 64. Actual v/s predicted tide at Port Aransas during Tropical Storm Charlie in 1996 (top) and Tropical Storm Josephine in 1998 (bottom).



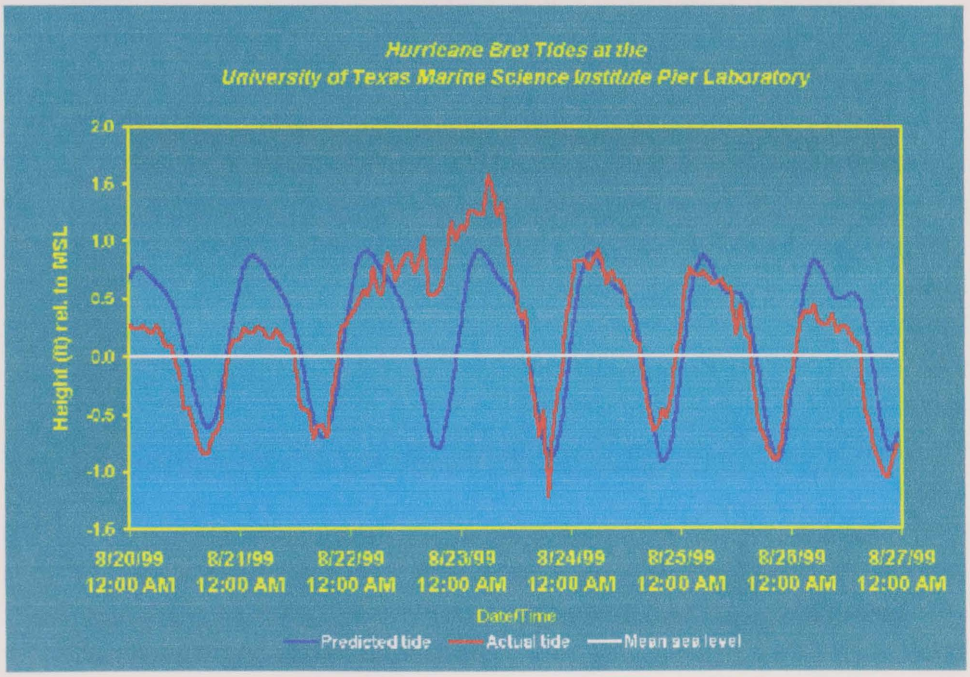




Figure 65. Actual v/s predicted tides at Port Aransas during Tropical Storm Frances in 1998(top) and Hurricane Brett in 1999.

Figure 66 Dunes at Mile 4 during tides generated by Tropical Storm Josephine in 1996. Prior to Josephine, the top of the post barely emerged above the dunes.

Table 7. Dune Erosion following Tropical Storm Josephine

| SITE | BEFORE | AFTER | DIFF (m) | DIFF(ft) |
|---|---|---|---|---|
| ACCESS RD #1 | 27.1 | 17.0 | 10.1 | 33.1 |
| MILE 1 | 11.1 | 6.1 | 5.0 | 16.4 |
| MILE 2 | 6.7 | -4.1 | 10.8 | 35.4 |
| MILE 3 | 6.3 | -5.0 | 11.3 | 37.1 |
| GULF SHORES | 8.6 | -3.1 | 11.7 | 38.4 |
| MILE 4 | 10.9 | 0.6 | 11.5 | 37.7 |
| MILE 5 | 8.3 | -3.4 | 11.7 | 38.4 |
| MILE 6 | 14.3 | -0.7 | 15.0 | 49.2 |
| MILE 7 | 13.5 | 3.6 | 9.9 | 32.5 |
| **MEAN** | — | --- | **10.8** | **35.2** |

Numbers in the BEFORE and AFTER columns are the distances measured from the dune line to the datum post at each site before and after Tropical Storm Josephine on September 7, 1996. Numbers are positive if the dunes are seaward of the posts and negative if they are landward. The DIFF columns are the difference in dune location relative to the post after the storm (i.e. the amount erosion of the dune front caused by Josephine). The mean of the BEFORE and AFTER columns has no real significance as the post positions are arbitrary but the measurement of erosion is absolute.

Table 8. List of tropical weather events and their effect on the beach, as recorded during BEACHobs from 1979-2000. Severity of effect on beach is indicated using an arbitrary rating of 0-5, from no discernible effect to major damage (see text for explanation).

| YEAR | DATE | STORM | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| 1979 | 09/13 | Hurricane Amelia | | | | | | |
| | 09/13-09/20 | "storms" | | | | | | |
| 1980 | 07/07 | Tropical Depression | | | | | | |
| | 08/09-08/10 | Hurricane Allen | | | | | | |
| | 09/08 | Tropical Depression | | | | | | |
| | 10/27 | Hurricane Jean | | | | | | |
| 1981 | 06/05 | Tropical Depression | | | | | | |
| | 06/15 | "storm" | | | | | | |
| | 09/05 | Tropical Storm Danny | | | | | | |
| | 09/29 | Tropical Depression | | | | | | |
| 1982 | 08/22 | Tropical Depression | | | | | | |
| | 10/01 | Tropical Depression | | | | | | |
| 1984 | 09/02-09/04 | "storm+norther" | | | | | | |
| 1985 | 07/29 | Tropical Wave | | | | | | |
| | 08/16 | Hurricane Danny | | | | | | |
| | 09/03 | Hurricane Elena | | | | | | |
| | 09/13 | Tropical Depression | | | | | | |
| | 09/17 | Tropical Wave | | | | | | |
| | 10/27 | Tropical Storm Juan | | | | | | |
| | 10/29 | Hurricane Juan | | | | | | |
| | 11/18-11/20 | Hurricane Kate | | | | | | |
| | 12/08 | Tropical Depression | | | | | | |
| 1986 | 06/26 | Hurricane Bonnie | | | | | | |

| YEAR | DATE | STORM | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| | 07/06 | Tropical Wave (Campeche) | | | | | | |
| 1986 | 07/06 | Tropical Wave (W. Florida) | | | | | | |
| | 08/05 | Tropical Disturbance | | | | | | |
| 1987 | 08/10 | Tropical Depression (Galveston) | | | | | | |
| 1988 | 09/13-09/15 | Hurricane Gilbert | | | | | | |
| | 11/22 | Tropical Storm Keith | | | | | | |
| 1989 | 06/16 | Tropical Depression | | | | | | |
| | 06/26 | Tropical Storm Allison | | | | | | |
| | 08/01 | Hurricane Chantal | | | | | | |
| 1990 | 08/08 | Hurricane Diana | | | | | | |
| | 10/02 | Tropical Wave | | | | | | |
| 1991 | 05/20-23 | Tropical Disturbance | | | | | | |
| | 07/07 | Tropical Depression | | | | | | |
| 1992 | 08/26-08/26 | Hurricane Andrew | | | | | | |
| | 10/01-10/03 | "Unknown disturbance" | | | | | | |
| 1993 | 06/20 | Tropical Storm Arlene | | | | | | |
| | 09/20-09/24 | Hurricane Gert | | | | | | |
| 1994 | 07/02 | Tropical Storm Alvarado | | | | | | |
| | 08/15 | Tropical Depression | | | | | | |
| | 09/15 | Tropical Storm Debbie | | | | | | |
| | 10/02 | Tropical Disturbance | | | | | | |
| 1995 | 06/05 | Hurricane Allison | | | | | | |
| | 07/31 | Tropical Storm Dean | | | | | | |
| | 08/02-08/07 | Hurricane Erin | | | | | | |
| | 08/10-08/12 | Hurricane Gabriella | | | | | | |

| YEAR | DATE | STORM | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| 1995 | 10/01-10/05 | Hurricane Opal | | | | | | |
| | 10/13 | Hurricane Roxanne | | | | | | |
| 1996 | 08/20-08/24 | Hurricane Dolly | | | | | | |
| | 10/05-10/07 | Tropical Depression #10 (Josephine) | | | | | | |
| 1998 | 08/22 | Hurricane Charley | | | | | | |
| | 09/03 | Hurricane Earl | | | | | | |
| | 09/11 | Tropical Storm Frances | | | | | | |
| | 09/19 | Tropical Storm #8 (Hermine) | | | | | | |
| | 09/28 | Hurricane Georges | | | | | | |
| | 10/25 | Tropical Disturbance | | | | | | |
| 1999 | 07/16 | Tropical Wave | | | | | | |
| | 08/21-08/23 | Hurricane Brett | | | | | | |
| | 09/06 | Tropical Depression | | | | | | |

coppice dunes and destroying mid-beach vegetation; 4, considerable erosion of the dune face, all coppice dunes destroyed; and 5, major dune erosion, creation of wash-over channels, damage to beachfront condominiums.

## 8. CONTRIBUTION OF HUMAN ACTIVITIES TO OBSERVED CHANGES

The visible effects of human activities on Mustang Island Gulf beach are obvious: the beach surface is rutted with vehicle tracks, the dunes are lined with piles of sand and debris, and heavy vehicles work almost daily, scraping and grading the sand. Does this obvious alteration of the beach exacerbate or ameliorate the erosional forces of wind and water? The present data series probably cannot differentiate between the effects of natural forces and the man-made activities over the long term. There is no doubt that short-term changes occur due to beach management and vehicle traffic. I have made numerous observations that the tide advances higher on the beach in locations where the beach is scraped compared to adjacent areas left untouched. Drivers are forced by high water to drive over areas of emerging coppice dunes, thus arresting dune growth. It has been more than two years since I've noted any lasting coppice-dune formation. Semipermanent but artificial longitudinal sand ridges are formed when grading is used to maintain driving lanes. This often lowers the level of the back-beach and, due to their unconsolidated nature, the ridges are easily broached by high tides. On the other hand, if the ridges are created near the shoreline they can stay the advance of water onto the back-beach.

There is some thought that the placement of weed and sand piles at the base of the dunes promotes dune stability and enhances the dunes as protection of the barrier island from storm surges. There is no doubt that the dune face has grown seaward, but there is no evidence that erosion from storms is arrested by the addition of the sand/weed piles. Without coppice dunes and with a depressed back-beach, the tide reaches the dunes rapidly. Also, the dune face is artificially steep and the material easily eroded by waves although, if left without further periodically dumped material, it ultimately becomes vegetated. The dune management procedures are constantly changing and are done on an erratic schedule. It is therefore not really possible to determine if they ultimately cause or arrest erosion. I have attempted to note during each survey whenever beach management is ongoing but an analysis of these data is beyond the scope of this report.

## 9. SUMMARY

An analysis has been made of data from 21 years of surveys, comprising nearly 3,000 separate observations of a 7.3-mile transect of Mustang Island Gulf beach. The data consists of measurements of beach widths and observational notes made bi-daily since 1979. The series comprises measurements made at one location since 1979 and at eight additional sites since 1983. There are gaps lasting up to two months in the data set. Erosion of the shoreline was observed following several tropical storm events. Principal among these were Hurricane Allen in 1980, Hurricane Gilbert in 1988, Tropical Storms Josephine in 1996 and Charley and Frances in 1998. In each of these cases, dune erosion was also observed but dune recovery occurred in the months following. In the case of Allen, the shoreline accreted dramatically as sand eroded from the dunes

was deposited seaward. Following a period of several years of accretion the shoreline eroded at a rate of 1.7 ft/year. Overall, however, from 1979 to the present (June 2000) there was essentially no shoreline erosion at the Gulf Shores site. Dune growth occurred in the post-Allen epoch at a rate of 1.6 ft/year. With the shoreline eroding and the dunes advancing, the beach has narrowed at all locations except near the access roads. At Gulf Shores the beach narrowed at an overall rate of over 7 ft/year since Hurricane Allen. Dune growth may have been aided by beach management procedures, but the data cannot differentiate between natural and man-induced changes. These rates of change are in agreement with historical records on Mustang Island of an erosional beach with rates of -2 to +5 ft/year (Morton, 1993). What the results show that other studies miss are the shorter-term changes on the order of months to years that exceed the long-term trend, both in erosion and accretion. Also documented are the immediate effects of numerous tropical storm events over the 21-year study period, and the subsequent recovery processes.

## 10. REFERENCES


Amos, A. F., 1979. Longhorn Reports: The IXTOC oil spill, Part I - Field Observations: July-November 1979. Final Report to NOAA/ERL and DOT/US Coast Guard under NOAA Contract No. NA79RAC00141. 281pp+Appendices.

Amos, A. F., (In prep). The relationship between astronomical tides and beach widths on a Texas barrier island Gulf beach. University of Texas Marine Science Institute, Technical Report.

Davis, R. A., 1972, Beach changes on the central Texas coast associated with hurricane Fern, September, 1971. Contributions in Marine Science, 16:89-98.

Davis, R. A, 1978. Beach sedimentology of Mustang and Padre Islands: a time-series approach. Journal of Geology 86:35-46.

Davis, R. A. and W. T. Fox, 1972. Coastal dynamics along Mustang Island, Texas. Technical Report 9, ONR Contract NONR 388-092, Western Michigan College. 68pp.

Davis, R. A. and W. T. Fox, 1975. Process-response patterns in beach and nearshore sedimentation: 1. Mustang Island, Texas. Journal of Sedimentary Petrology, 45(4):852-865; Figs 1-10.

Ellis, M. J., 1986. The Hurricane Almanac, Texas Edition. Michael J. Ellis, Disaster Resources, 1234 Nile #44, Corpus Christi, Texas 78412; 168 pp.

Emery, K. O., 1961. A simple method of measuring beach profiles. Limnology and Oceanography, 6:90-93.

Morton, R. A. and M. J. Pieper, 1977. Shoreline changes on Mustang Island and North Padre Island (Aransas Pass to Yarborough Pass): an Analysis of historical changes of the Texas Gulf shoreline. Geological Circular 77-1, Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas 78712; 45pp.

Morton, R. A., C. Jennings and L. Remington, 1993. Shoreline movement along developed beaches of the Texas Gulf coast: a users' guide to analyzing and predicting shoreline changes. Open-File Report 93-1, Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78713-7508; 78pp.

Morton, R.A., 1993. Historical shoreline changes along segments of the Texas coastline (map). Bureau of Economic Geology, The University of Texas at Austin, Austin, TX

National Oceanic and Atmospheric Administration, 1996. Combined Coastal Management Program and Final Environmental Impact Statement for the State of Texas, Parts I-VII + appendices. Office of Ocean and Coastal Resource Management, USDC/NOAA, 1305 East-West Highway, N/ORM3, Silver Spring, MD 20910 and The State of Texas, Stephen F. Austin Bldg., 1700 N. Congress Ave., Austin, TX 78701-1495.

Nummedal, D., 1982. Sedimentary processes and environments along the Louisiana-Texas coast. Field trip guidebook, Annual Mtg. Geological Society of America, New Orleans, Louisiana, October 1982.

Smith, N. P., 1985. Numerical simulation of bay-shelf exchanges with a one-dimensional model. Contributions in Marine Science, 28:1-13.

Snedden, J. W. and D. Nummedal, 1990. Coherence of surf zone and shelf current flow on the Texas (U.S.A.) coastal margin: implications for interpretation of paleo-current measurements in ancient coastal sequences. Sedimentary Geology, 67:221-236.

Snedden, J. W., D. Nummedal and A. F. Amos, 1988. Storm- and fair-weather combined flow on the central Texas continental shelf. Journal of Sedimentary Petrology, 58(4):580-595.

White, W. A., R. A. Morton, R. S. Kerr, W. D. Kuenzi, and W. B. Brogden, 1978. Land and water resources, historical changes, and dune criticality: Mustang and North Padre Islands, Texas. Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78713; 46pp + Chart.

**Acknowledgments**

Andrea Wickham performed much of the task of searching through the data and correcting errors. Lynn Amos provided invaluable assistance in preparing the report. Some of the earlier BEACHobs surveys were done by Bill Heald and Scott Holt in my absence. The BEACHobs surveys were funded by the author. Support for analyzing the data and preparing this report was provided by the National Oceanic and Atmospheric Administration, Award No. NA87OZ0251, under Texas General Land Office Contract 98-291R, Coastal Management Program Cycle 3.

This contribution is Technical Report #TR/00-002 of The University of Texas at Austin, Marine Science Institute, 750 Channel View Drive, Port Aransas, Texas 78373-5015.

APPENDIX I : LOCATION OF BEACH SIGNS, MILE MARKERS, WALKWAYS AND BEACH-FRONT BUILDINGS ALONG THE BEACHobs SURVEY TRANSECT IN 1983, 1992, AND 2000

| DIST | CODE | DESCRIPTION | CODE | DESCRIPTION | CODE | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | 1983 | | 1992 | | 2000 |
| 0.00 | ROAD | ACCESS ROAD 1 | ROAD | ACCESS ROAD 1 | MIL0 | ACCESS ROAD 1 |
| 0.02 | N | N | SIGN | FREE PARKING | N | N |
| 0.03 | N | N | N | N | GARB | TRASH BARREL |
| 0.04 | MARK | PORT A MILE MARKER #3 | N | N | N | N |
| 0.05 | N | N | GARB | TRASH CAN ON POST | N | N |
| 0.06 | N | N | N | N | MARK | MARKER 27 |
| 0.10 | N | N | GARB | TRASH CAN ON POST | N | N |
| 0.13 | N | N | MARK | MARKER 27 | N | N |
| 0.16 | MARK | NUECES CO. MILE 17 | GARB | TRASH CAN ON POST | MARK | MARKER 28 |
| 0.17 | N | N | MARK | NUECES CO. MILE 17 | N | N |
| 0.20 | SIGN | 15 MPH | N | N | N | N |
| 0.23 | N | N | MARK | MARKER 28 | N | N |
| 0.24 | N | N | GARB | TRASH CAN ON POST | N | N |
| 0.29 | N | N | GARB | 2 TRASH CANS | N | N |
| 0.30 | N | N | N | N | GARB | TRASH BARREL |
| 0.31 | N | N | GARB | TRASH CAN ON POST | N | N |
| 0.33 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 0.36 | N | N | N | N | MARK | MARKER 29 |
| 0.37 | N | N | SIGN | NO PARKING/NO DRIVING | N | N |
| 0.43 | SIGN | DRIVE DESIGNATED ROAD | SIGN | $15-$400 FINE LITTERING | N | N |
| 0.44 | N | N | SIGN | 15 MPH | N | N |
| 0.46 | N | N | N | N | SIGN | 15 MPH |
| 0.47 | SIGN | $200 FINE LITTERING | N | N | MARK | MARKER 30 |
| 0.48 | N | N | GARB | 2 TRASH CANS | N | N |
| 0.49 | N | N | SIGN | CITY LIMITS | GARB | TRASH BARREL |
| 0.50 | SIGN | NO PARKING WITHIN 25 | N | N | N | N |
| 0.57 | AUTO | 1ST BURIED CAR | N | N | N | N |
| 0.58 | N | N | N | N | MARK | MARKER 31 |
| 0.60 | AUTO | 2ND CAR & CARS IN DUNE | N | N | N | N |
| 0.64 | N | N | POST | IRON POST IN DUNES | N | N |
| 0.66 | SIGN | 15 MPH SPEED LIMIT | N | N | N | N |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.67 | N | N | N | N | SATR | SKIDOCAN |
| 0.76 | N | N | N | N | SIGN | 15 MPH |
| 0.78 | FENC | END OF OLD DUNELINE | N | N | N | N |
| 0.82 | SIGN | NO DRIVING IN DUNES | N | N | N | N |
| 0.91 | N | N | SIGN | NO DRIVING IN DUNES | MARK | MARKER 34 |
| 0.93 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 0.98 | N | N | N | N | MIL1 | MILE 1 |
| 0.99 | N | N | MIL1 | MILE 1 | N | N |
| 1.07 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 1.08 | N | N | N | N | SIGN | 15 MPH |
| 1.16 | MARK | NUECES CO. MILE 16 | MARK | NUECES CO. MILE 16 | N | N |
| 1.17 | N | N | N | N | MARK | MARKER 37 |
| 1.20 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 1.21 | SIGN | 15 MPH | N | N | N | N |
| 1.22 | N | N | TREE | DRIFTWOOD TREE | N | N |
| 1.28 | N | N | CND2 | RED FLAG IN DUNES | N | N |
| 1.29 | N | N | N | N | MARK | MARKER 38 |
| 1.37 | N | N | TREE | DRIFTWOOD TREE | N | N |
| 1.38 | SIGN | NO DRIVING IN DUNES | CND2 | RED FLAGS IN DUNES | GARB | TRASH BARREL |
| 1.42 | N | N | N | N | COND | WALKWAY |
| 1.45 | SIGN | 15 MPH | N | N | N | N |
| 1.49 | N | N | N | N | MARK | MARKER 40 |
| 1.52 | SIGN | NO DRIVING IN DUNES | N | N | N | N |
| 1.53 | N | N | N | N | COND | BEACHWALK 1 WALKWAY |
| 1.57 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 1.58 | N | N | SIGN | 15 MPH | MARK | MARKER 41 |
| 1.66 | N | N | N | N | COND | BEACHWALK 2 WALKWAY |
| 1.67 | N | N | COND | CASADEL WALKWAY | N | N |
| 1.68 | N | N | N | N | GARB | TRASH BARREL |
| 1.70 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 1.71 | N | N | CND2 | CENTER OF CASADEL | COND | CASADEL WALKWAY |
| 1.73 | COND | CASA DEL CORTEZ WALK | N | CASA DEL CORTEZ WALK | N | CASA DEL CORTEZ WALK |
| 1.75 | N | N | TREE | CREOSOTED PILING | N | N |
| 1.77 | N | N | N | N | MARK | MARKER 43 |
| 1.78 | N | N | SIGN | 15 MPH | N | N |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.85 | N | | WREK | CIVIL WAR WRECK SITE | N | N |
| 1.87 | WREK | CIVIL WAR MINESWEEP | N | N | MARK | MARKER 44 |
| 1.94 | SIGN | 15 MPH | N | N | N | N |
| 1.95 | GARB | EX-HORSE CANOPY | N | N | N | N |
| 1.96 | N | N | N | N | MIL2 | MILE 2 |
| 1.99 | SIGN | NO DRIVING IN DUNES | SIGN | NO DRIVING IN DUNES | N | N |
| 2.02 | N | N | SIGN | 15 MPH | N | N |
| 2.06 | N | N | N | N | MARK | MARKER 46 |
| 2.07 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 2.14 | MARK | NUECES CO. MILE 15 | N | N | N | N |
| 2.16 | N | N | MARK | NUECES CO. MILE 15 | MARK | MARKER 47 |
| 2.20 | SIGN | 15 MPH | N | N | N | N |
| 2.22 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 2.27 | N | N | N | N | SIGN | 15 MPH |
| 2.36 | N | N | N | N | GARB | TRASH BARREL |
| 2.39 | SIGN | $200 FINE LITTERING | DUNE | CHRISTMAS TREES | N | N |
| 2.47 | N | N | N | N | MARK | MARKER 50 |
| 2.48 | COND | FLATO RANCH | N | N | N | N |
| 2.54 | FENC | FLATO FENCE ON DUNES | N | N | N | N |
| 2.57 | N | N | N | N | GARB | TRASH BARREL |
| 2.59 | SIGN | 15 MPH | N | N | N | N |
| 2.65 | N | N | N | N | SIGN | FREE PARKING |
| 2.69 | N | N | TREE | PILE OF DRIFTWOOD | N | N |
| 2.72 | N | N | N | N | GARB | TRASH BARREL |
| 2.76 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 2.79 | N | N | SIGN | 15 MPH | SIGN | 15 MPH |
| 2.80 | N | N | TREE | DRIFTWOOD TREE | N | N |
| 2.82 | N | N | N | N | COND | NEW BLUE-ROOF HOUSE |
| 2.84 | N | N | N | N | GARB | TRASH BARREL |
| 2.90 | SIGN | NO DRIVING IN DUNES | N | N | N | N |
| 2.93 | N | N | N | N | SIGN | 15 MPH |
| 2.96 | N | N | NOTE | MY BEACHOBS MILE 3 | N | N |
| 2.98 | MARK | NUECES CO. MILE 14 | N | N | N | N |
| 3.03 | N | N | SIGN | $200 FINE LITTERING | GARB | TRASH BARREL |
| 3.05 | SIGN | 15 MPH | N | N | N | N |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3.07 | SIGN | NO PARKING WITHIN 25 FT | N | N | N | N |
| 3.10 | N | N | MIL3 | MY MILE 3 POST | N | N |
| 3.13 | SIGN | NO DRIVING IN DUNES | N | N | MIL3 | MILE 3 |
| 3.14 | N | N | POST | POST ONLY IN DUNES | N | N |
| 3.16 | N | N | MARK | NUECES CO MILE 14 | N | N |
| 3.19 | SIGN | UP TO $200 FINE FOR | N | N | N | N |
| 3.22 | N | N | N | N | SIGN | FREE PARKING |
| 3.25 | N | N | SIGN | 15 MPH | N | N |
| 3.31 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 3.33 | N | N | N | N | GARB | TRASH BARREL |
| 3.41 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 3.43 | GARB | CABLE PROTRUDING | N | N | N | N |
| 3.44 | N | N | VEGE | MORNING GLORY | N | N |
| 3.45 | N | N | N | N | MARK | MARKER 60 |
| 3.56 | N | N | GARB | PILES WEED & SAND | GARB | TRASH BARREL |
| 3.62 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 3.63 | N | N | COND | LA MIRAGE WALKWAY | N | N |
| 3.64 | N | N | N | N | COND | LA MIRAGE WALKWAY |
| 3.65 | COND | WINDJAMMER WALKWAY | N | N | N | N |
| 3.66 | N | N | CND2 | LA MIRAGE END | N | N |
| 3.68 | N | N | N | N | MARK | MARKER 62 |
| 3.69 | N | N | SIGN | 15 MPH SPEED LIMIT | SIGN | 15 MPH |
| 3.71 | SIGN | STOP FOR PEDESTRIANS | N | N | COND | MARINER'S WATCH WALK |
| 3.73 | N | N | N | N | GARB | TRASH BARREL |
| 3.74 | N | N | COND | GULF SHORES | N | N |
| 3.75 | COND | GULF SHORES | N | N | N | N |
| 3.76 | SIGN | PEDESTRIAN CROSSING | N | N | COND | GULF SHORES |
| 3.78 | N | N | N | N | GARB | TRASH BARREL |
| 3.79 | SIGN | STOP FOR PEDESTRIANS | N | N | N | N |
| 3.81 | SIGN | 15 MPH | N | N | N | N |
| 3.89 | N | N | N | N | GARB | TRASH BARREL |
| 3.90 | N | N | COND | MUSTANG TOWERS | N | N |
| 3.91 | COND | MUSTANG TOWERS | N | N | N | N |
| 3.92 | N | N | COND | END OF WALKWAY | N | N |
| 3.93 | COND | MUSTANK TOWERS WALK | N | N | COND | MUSTANG TOWERS WALK |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.95 | N | N | SIGN | 15 MPH | N | N |
| 3.96 | N | N | N | N | GARB | TRASH BARREL |
| 4.00 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 4.11 | MARK | NUECES CO. MILE 13 | N | N | N | N |
| 4.16 | N | N | MARK | NUECES CO. MILE 13 | N | N |
| 4.17 | N | N | COND | PORT ROYAL WALKWAY | N | N |
| 4.19 | N | N | N | N | MIL4 | MILE 4 |
| 4.20 | N | N | N | N | GARB | TRASH BARREL |
| 4.22 | SIGN | 15 MPH | N | N | N | N |
| 4.24 | N | N | COND | NORTH END PORT ROYAL | GARB | TRASH BARREL |
| 4.26 | N | N | COND | PORT ROYAL WALKWAY | N | N |
| 4.27 | N | N | N | N | COND | PORT ROYAL WALKWAY |
| 4.30 | N | N | N | N | GARB | TRASH BARREL |
| 4.32 | N | N | SIGN | 15 MPH | N | N |
| 4.34 | N | N | COND | SOUTH END PORT ROYAL | N | N |
| 4.37 | N | N | N | N | GARB | TRASH BARREL |
| 4.41 | SIGN | $200 FINE LITTERING | GARB | PILE WEED & SAND | N | N |
| 4.49 | N | N | NOTE | MY ESTIMATE OF 4.5 M | N | N |
| 4.50 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 4.51 | N | N | N | N | GARB | TRASH BARREL |
| 4.60 | SIGN | 15 MPH | N | N | N | N |
| 4.61 | N | N | SIGN | 15 MPH | N | N |
| 4.63 | N | N | POST | OLD POST | GARB | TRASH BARREL |
| 4.64 | SIGN | NO DRIVING IN DUNES | N | N | N | N |
| 4.71 | N | N | N | N | GARB | TRASH BARREL |
| 4.72 | N | N | TREE | PILE OF DRIFTWOOD | N | N |
| 4.79 | N | N | N | N | GARB | TRASH BARREL |
| 4.80 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 4.83 | N | N | GARB | PILE WEED & SAND | GARB | TRASH BARREL |
| 4.90 | SIGN | STOP CHILDREN AT PLAY | SIGN | 15 MPH | GARB | TRASH BARREL |
| 4.92 | N | N | N | N | COND | SANDPIPER WALKWAY |
| 4.93 | COND | SEA GULL WALKWAY | COND | SEA GULL WALKWAY | N | N |
| 4.94 | MIL5 | MILE 5 | COND | SEA GULL | N | N |
| 4.98 | SIGN | 15 MPH | N | N | N | N |
| 5.03 | N | N | MIL5 | OVERSHOT | N | N |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.06 | N | N | N | N | GARB | TRASH BARREL |
| 5.07 | N | N | POST | OLD POST | N | N |
| 5.10 | COND | CRANES/FLAGS ON DUNE | COND | SANDPIPER | N | N |
| 5.11 | N | N | COND | SANDPIPER WALKWAY | N | N |
| 5.12 | MARK | NUECES CO. MILE 12 | SIGN | NO LIFEGUARD ON DUTY | MIL5 | MILE 5 |
| 5.15 | N | N | DUNE | CHRISTMAS TREES | N | N |
| 5.19 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 5.23 | N | N | SIGN | 15 MPH | N | N |
| 5.26 | N | N | N | N | SIGN | 15 MPH |
| 5.34 | N | N | SIGN | PEDESTRIAN CROSSING | COND | LOST COLONY |
| 5.37 | N | N | CND2 | END OF LOST COLONY | N | N |
| 5.39 | SIGN | STOP FOR PEDESTRIANS | N | N | N | N |
| 5.40 | SIGN | 15 MPH | SIGN | 15 MPH | N | N |
| 5.41 | N | N | N | N | GARB | TRASH BARREL |
| 5.46 | POST | POSTS NEAR DUNES | GARB | PILE WEED & SAND | N | N |
| 5.50 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 5.54 | N | N | N | N | COND | RETREAT WALKWAY |
| 5.56 | N | N | GARB | PILE DRIFTWOOD & SAND | N | N |
| 5.64 | DUNE | HAWN DUNE RESTOR | N | N | N | N |
| 5.65 | N | N | TREE | DRIFTWOOD LOGS | N | N |
| 5.68 | N | N | COND | HAWN HOUSE WALKWAY | N | N |
| 5.69 | COND | HAWN HOUSE WALKWAY | N | N | N | N |
| 5.70 | N | N | N | N | COND | HAWN WALKWAY |
| 5.71 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 5.72 | DUNE | END HAWN DUNE RESTOR | N | N | N | N |
| 5.76 | N | N | SIGN | HP GAS LINE LOVERA | SIGN | HIGH PRESSURE PIPELINE |
| 5.81 | N | N | DUNE | CHRISTMAS TREE | N | N |
| 5.87 | N | N | TREE | DRIFTWOOD LOG | N | N |
| 5.93 | N | N | TREE | PILE DRIFTWOOD & SAND | N | N |
| 5.99 | SIGN | 15 MPH | N | N | N | N |
| 6.01 | N | N | POST | OLD NUECES CO. 11? | N | N |
| 6.02 | N | N | DUNE | CHRISTMAS TREE | MIL6 | MILE 6 |
| 6.03 | COND | 1ST PRIVATE HOUSE | N | N | N | N |
| 6.04 | N | N | COND | 2ND PRIVATE HOUSE | COND | 2ND PRIVATE HOUSE |
| 6.05 | COND | 2ND PRIVATE HOUSE | N | N | N | N |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6.10 | MARK | NUECES CO. MILE 11 | SIGN | 15 MPH | N | N |
| 6.16 | N | N | MARK | NUECES CO. MILE 11 | N | N |
| 6.23 | WREK | MISS OLIMPIA | SIGN | 1ST PIPELINE | N | N |
| 6.24 | N | N | WREK | MISS OLIMPIA | GARB | TRASH BARREL |
| 6.25 | COND | FIRST ADMIRAL'S ROW | N | N | N | N |
| 6.27 | N | N | N | N | COND | ADMIRALS ROW WALK |
| 6.28 | SIGN | $200 FINE LITTERING | SIGN | 15 MPH | N | N |
| 6.29 | N | N | COND | ADMIRAL'S ROW WALK | N | N |
| 6.30 | N | N | N | N | GARB | TRASH BARREL |
| 6.31 | COND | LAST ADMIRAL'S ROW | N | N | N | N |
| 6.33 | N | N | COND | LAST ADMIRAL'S ROW | N | N |
| 6.36 | N | N | N | N | SIGN | 15 MPH |
| 6.40 | N | N | COND | MAYAN PRINCESS WALK | COND | MAYAN PRINCESS WALK |
| 6.44 | N | N | N | N | GARB | TRASH BARREL |
| 6.49 | N | N | SIGN | NO DRIVING IN DUNES | N | N |
| 6.52 | N | N | SIGN | 15 MPH | N | N |
| 6.58 | SIGN | 2ND PIPELINE | N | N | N | N |
| 6.62 | N | N | GARB | PILES WEED & SAND | GARB | TRASH BARREL |
| 6.69 | N | N | SIGN | 2ND PIPELINE | N | N |
| 6.70 | POST | ON HIGH DUNE | N | N | SIGN | OLD PIPELINE SIGN |
| 6.71 | N | N | SIGN | 15 MPH | N | N |
| 6.73 | N | N | TREE | LONG DRIFTWOOD TREE | SIGN | CITY CORPUS CHRISTI |
| 6.78 | N | N | N | N | SIGN | PIPELINE |
| 6.80 | SIGN | 3RD PIPELINE | N | N | N | N |
| 6.88 | SIGN | $200 FINE LITTERING | N | N | N | N |
| 6.90 | N | N | SIGN | 15 MPH | N | N |
| 6.96 | N | N | GARB | PILE SAND & DRIFTWOOD | N | N |
| 7.00 | N | N | NOTE | OVERSHOT OLD MILE 7 | N | N |
| 7.02 | N | N | N | N | MIL7 | MILE 7 |
| 7.08 | N | N | MIL7 | NEW MILE 7 POST | N | N |
| 7.09 | MARK | NUECES CO. MILE 10 | N | N | N | N |
| 7.16 | N | N | MARK | NUECES CO. MILE 10 | N | N |
| 7.24 | N | N | SIGN | 15 MPH | N | N |
| 7.28 | N | N | POST | OLD POST IN DUNES | N | N |
| 7.34 | ROAD | ACCESS ROAD 2 | ROAD | ACCESS ROAD 2 | ROAD | ACCESS ROAD 2 |